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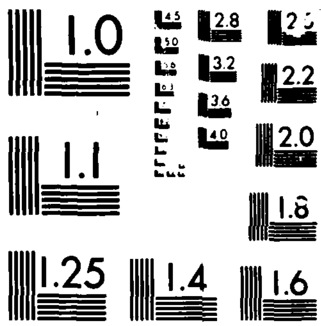

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AFWAL-TR-81-4111

Volume II

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

Volume II - Appendices (Phase IV - Engineering Specifications)

AD-A167 022

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P. O. Box 2691
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This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

JOSEPH A. MOYZIS, JR.
Nondestructive Evaluation Branch
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FOR THE COMMANDER

D. M. FORNEY, JR., Chief
Nondestructive Evaluation Branch
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20. Abstract (Continue on reverse side if necessary and identify by block number)

A design study has been conducted to establish an engineering specification for an integrated inspection system that will be used to implement the Retirement for Cause (RFC) maintenance philosophy on gas turbine engine disks and spacers. The system specified by this study emphasizes equipment reliability, flexibility, component throughput and accountability required for 1985 overhaul facility implementation through an Air Force manufacturing technology program. NDE technology needs for far term (post 1985) overhaul implementation of optimal RFC inspections are discussed in terms of necessary research programs which should be conducted in parallel to the manufacturing technology effort.

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FOREWORD

This work was performed under Materials Laboratory Contract F33615-80-C-5049. The Air Force project manager was Mr. K. D. Shimmin, AFWAL/MLLP, and the work was contracted to the Materials and Mechanics Technology Laboratories of Pratt & Whitney Aircraft (P&WA) Group Government Products Division, West Palm Beach, Florida. The Program Manager was J. S. Cargill reporting to J. A. Harris, Jr., Supervisor of Mechanics of Structures who reports to M. C. VanWanderham, Manager of Mechanics of Materials and Structures. R. L. Shambaugh was Program Coordinator.

Dr. James E. Doherty was the original P&WA Program Manager, and the authors wish to acknowledge the many special contributions which he has made.

The authors wish to acknowledge the members of the RFC team, who diligently conducted research for their respective program tasks and prepared thorough engineering specifications for the RFC Inspection System. The contributors and their tasks follow: J. M. La Grotta (P&WA/Commercial Products Division), eddy current equipment, signal processing and interface protocol; Dr. R. V. Harris, Jr. (P&WA/Government Products Division), ultrasonic test instrumentation; Dr. J. E. Doherty and Amos S. Greer (Southwest Research Institute), mechanical scanning; H. L. Grothues (Southwest Research Institute), control software and data management; F. Trindade and J. Oosterlink (Giffels Associates), parts handling and facility layout; Dr. C. A. Rau (Failure Analysis Associates), inspection system performance; Prof. R. B. Thompson (Ames Research Laboratory), advanced NDE methods; Dr. R. W. Schafer (Georgia Institute of Technology) and Dr. R. S. Williams (United Technologies Research Institute Technology), signal processing.

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RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX A
EQUIPMENT SPECIFICATION FOR A COMPUTERIZED EDDY CURRENT INSTRUMENT

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APPENDIX A

EQUIPMENT SPECIFICATION FOR A COMPUTERIZED EDDY CURRENT INSTRUMENT

1.0 SCOPE

This specification contains the minimum technical and performance requirements for a computer-controlled eddy current instrument used for nondestructive inspection. The equipment is intended for use by the United States Air Force (USAF) at depot nondestructive evaluation (NDE) facilities in conjunction with an automated eddy current test system. The instrument shall include all probes, connector assemblies, maintenance manuals, operating instructions, diagnostic programs (software), and other necessary ancilliary equipment as specified herein.

2.0 APPLICABLE DOCUMENTS

The following documents of the issue in effect on the date of the invitation for bids or requests for proposal form a part of this specification to the extent specified herein.

2.1 Government Documents

2.1.1 Specifications

MIL-T-28800B	Test Equipment for Use with Electrical and Electronic Equipment, General Specification for
MIL-I-45208	Inspection System Requirements
MIL-M-3874	Manuals Technical; General Style and Format Requirements
MIL-T-18303	Test Procedures, Reproduction, Acceptance and Life for Aircraft Electronic Equipment, Format for

2.1.2 Standards

MIL-STD-810	Environmental Test Methods
MIL-STD-831	Test Reports, Preparation of
MIL-STD-109	Quality Assurance Terms and Definitions

2.1.3 Other Publications

DI-M-5120	Instruction Manual - Minimum Specification Requirements

2.2 Nongovernment Documents

ANSI Y32.14* - 1973 Graphic Symbols for Logic Diagrams.

EIA std. RS-310-C Standard for Racks, Panels, and Equipment.

UL 1410* Standard for Television Receivers and Video Products.

IEEE Std. 100* "IEEE Standard Dictionary of Electrical and Electronic Terms."

ANSI/IEEE Std. 488* "IEEE Standard Digital Interface for Programmable Instrumentation."

Draft* "Code and Format Convention for use with IEEE Std. 488A - 1978.

2.3 Document Sources

Copies of Specifications and Standards and other publications referenced in this specification, except those indicated (*), may be obtained from the procuring activity.

3.0 REQUIREMENTS

3.1 General Requirements

The equipment will be primarily designed to perform eddy current testing on aircraft engine components by USAF nondestructive evaluation personnel at depot level.

The equipment will be designed and manufactured in a manner that will result in commercially reproducible equipment when procured in quantity for inventory. In addition, the equipment will be capable of precise and repeatable calibration from unit to unit and afford a high degree of long-term stability. The equipment will be capable of self-diagnostics, both with and without a defined system controller (external computer), for the purpose of determining the current operational state of all key elements of the instrument.

The instrument will have sufficient internal computational capacity to perform all functions described herein on a manual basis. In addition the instrument will be capable of bidirectional communication with a system controller (computer) over an Instrument Bus (IEEE 488/1978).

3.1.1 Classification

The equipment will conform to the general requirement of MIL-T-28800B, Type III, Class 6, Style F, except as modified by this specification. When specifications conflict, this specification will take precedence.

3.2 Safety

The equipment will incorporate the safety features necessary to safeguard personnel during installation, operation, maintenance, repair, and interchanging of components.

With the exception of radiation energy measurement, the equipment will incorporate the safety features per MIL-T-28800B, Paragraph 3.2.

Protection will be provided from leakage current in excess of 1 ma peak ac and dc from any accessible conductive parts of the equipment (including control shafts with knobs removed and recessed calibration or adjustment controls) for any position of the power switch(es) in accordance with the appliance shock hazard test of UL 1410, Section 12 and 13. All accessible electrically conductive surfaces of the equipment, when fully assembled and operating, will be at earth ground potential.

3.3 Equipment Description

The major components of each system will consist of the following items:

3.3.1 Eddy Current Instrument

3.3.2 Set of Probes, 1 each Typical

A specialized set of probes will be required for some applications

Probe	*Part No.*	*Description/Generic*
Bolthole 3/8 in.*	H-3/8	Differential bolthole probe for 3/8 in. dia holes
Cooling hole 0.100 in.*	H-100	Generic differential probe for 100 mil cooling hole
Rim slot 1st fan	RS 1st fan F100	Specialized probe — F100 for first fan rim slots
Knife edge 1st turbine	KE 1st turb F100	Specialized probe — F100 first turbine knife edge

*Note: Probes, which have generic application, will carry a generic designation.

3.3.3 Probe Cable and Interconnection Assembly, 1 each

3.3.4 Power Cord, 1 each

3.3.5 IEEE 488/1978, 4 meter cable, 1 each

3.3.6 IEEE 488/1978, 1 meter cable, 1 each

3.3.9 Digital and Analog Extender Cables and/or Boards (as required for service)

3.3.10 Instrument Manuals, 1 each

3.3.11 Maintenance Manuals, 1 each

3.3.12 Diagnostic Software and Listings on Machine Readable Form for Control Processor, 1 copy.

3.4 Detailed Equipment Specification

3.4.1 Instrument Description

The instrument will be capable of both externally programmable and manual operations. The instrument will be constructed in a manner that facilitates maintenance and permits interchangeability while affording a potential means for replacement of cards, module, or components.

The operating range of this equipment will be 0°C to 50°C and nonoperating or storage conditions of −20°C to 80°C and a relative humidity of 0 to 90% noncondensing. The equipment will be capable of transport at altitudes of 12,000 m (40,000 ft.) nonoperating.

3.4.2 Enclosure

The enclosure will conform with the requirements of RS-310-C, and the physical dimensions will not exceed: 30.5 cm (12 inches) high × 48.3 cm (19 inches) wide × 56 cm (22 inch) deep and will be rack mountable in a standard 19 in. relay rack (RS-310-C). Two sets of carrying handles will be provided; one set on the front of the instrument and the other to be located on the side panels.

3.4.2.1 Protective Covers Not Required

3.4.2.2 Identification Plates

Identification plates should be mounted on the rear panel of the enclosure in accordance with the Marking and Identification Requirements of Paragraph 3.7.

3.4.3 Power Supply

The instrument will be capable of operation on 115/230 volts, 50/60 hertz AC line voltage. Switching between 115 and 230 volts should be external and not require tools. The power cord should be separable from the enclosure and a minimum of 1.8 m (6 ft.) long.

3.4.4 System Controller/Controls

Programmable and manual controls will be used to adjust all instrument functions, (except those used for internal calibration and scope intensity, alignment and focus). Adjustment of all controls will not interact with each other. Manual control is required when the instrument is in the programmable mode and under control of the system controller. A means to allow selective activation of manual controls will be provided. This means will be programmable through the remote interface and individually selectable at the function level. An LED or other display mechanism will be employed to indicate which controls are enabled for manual use. Upon powerup, the instrument will awake in the manual mode. In addition, during the power-up operation, the instrument will determine and inform both the system controller and the operator that it is in a power-up state and has undergone a self-test.

All communications to the system controller (external computer) will be through the IEEE 488A/1978 Instrument Bus.

The internal instrument processor will be an industry standard multiple source microprocessor capable of 16-bit binary arithmetic with 32-bit intermediate products. Sufficient nonvolatile internal memory will be provided to store the operational programs of the instrument plus an area of sufficient size to log hardware error conditions. The number of entries and contents of the hardware error log will be accessible both through a manual interrogation and through the system controller. In addition upon request, the instrument will provide the version/revision identification number of its internal programming, serial number, and the serial numbers of modules inserted if applicable.

3.4.5 Operational Speed

When in the operating mode, all functions will be complete within one tenth of a second of initiation. When in the programmable mode, operations will be complete within one millisecond of receipt of the command. The only exception being that external commands to balance will be completed within 100 milliseconds of issue.

3.4.6 Overall Instrument Sensitivity

The instrument and its probes will demonstrate an overall sensitivity to detect a 10 × 3 mil elliptical-shaped crack with an electronic signal to noise ratio of 10 to 1 in the following geometries in both Ti 6-4 and IN-100.

A. A bolthole or cooling hole crack starting at edge lying parallel to a radius line (see Figure A-1).

B. A crack on the edge of a blade slot (see Figure A-2).

C. A crack located on a knife edge (see Figure A-3).

D. A crack in an elliptical balance flange scallop (see Figure A-4).

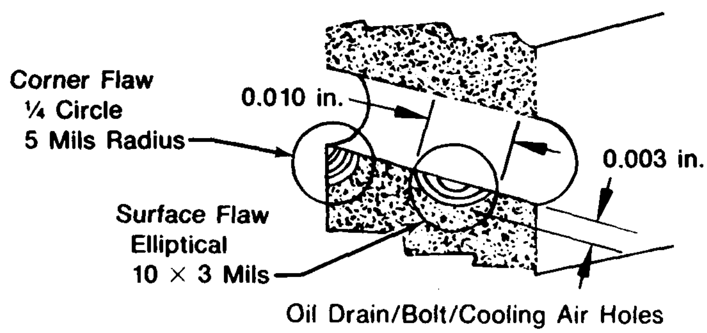


Figure A-1. Bolt/Cooling Hole Crack Standards

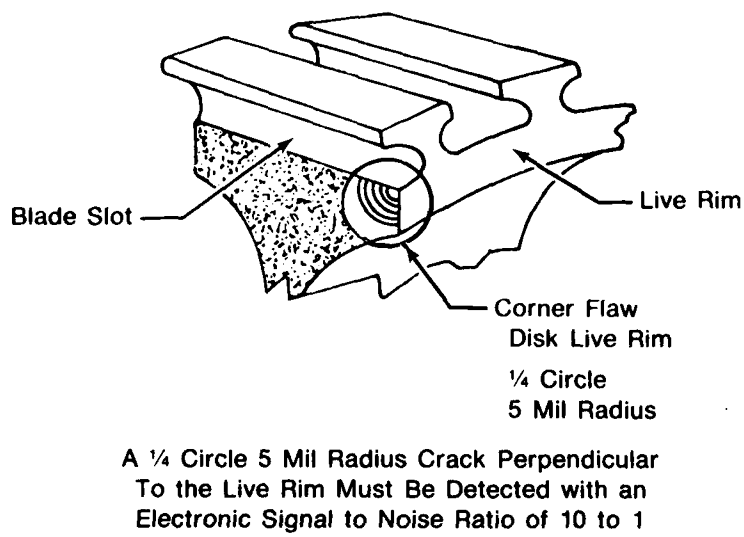
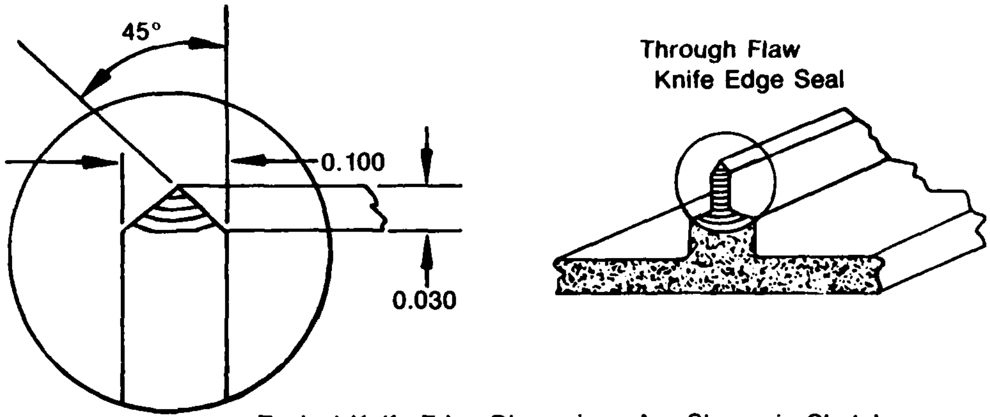


Figure A-2. Blade Slot Crack Standard



Typical Knife Edge Dimensions Are Shown in Sketch.
Detection Is Required when Crack Is 0.030 in.
Deep as Measured from Tip of Knife Edge

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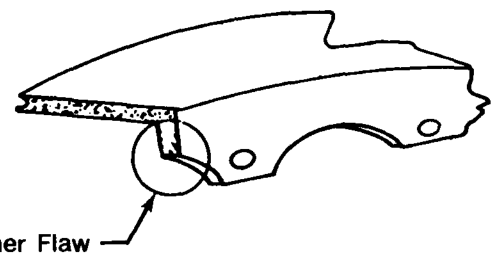
Figure A-3. Knife Edge Crack Standards



Corner Flaw
Balance Flange Scallop

¼ Circle
5 Mil Radius

A ¼ Circle 5 Mil Radius Crack Must Be
Detected with an Electronic Signal to
Noise Ratio of 10 to 1

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Figure A-4. Elliptical Balance Flange Scallop

3.4.7 Power Fail Recovery

In the event of a power failure, the state of the instrument controls will be maintained for at least two hours. The operator or system controller will be notified of the occurrence. If a change of instrument state was in progress during the power fail, the instrument will specifically notify the operator or system control as to the status of that function; for example, a balance command was in progress during a power failure.

3.4.8 Overall Instrument Bandwidth

The instrument analog sections will have an effective overall bandwith of 1 kHz ± 1 db as measured at the output of the analog section. For those portions of the instrument where information flow is digital, the effective bandwidth of the digital data bus will be sufficient to allow for a sampling rate of 3 kHz per channel of the analog signals. All A/D converters will be preceded by an anti-aliasing filter of at least 40 db/decade at the appropriate cutoff frequency.

The A/D conversion will be at least 12 bits in length and both linear and accurate to ±1 bit. Sampling time for the A/D process will be accurate to 0.01% of the sampling interval.

3.4.9 AC Line Noise Suppression and Voltage Variation

An RFI line filter will be installed on the AC supply voltage as close to the enclosure entry as is practical. This line filter will provide at least 30 db noise suppression at 50 kHz, and 60 db suppression at 1 mHz and above.

In addition the instrument will function within specification for worst case line voltage and frequency variations of ±5%.

3.4.10 Long-Term Stability

The instrument output should be stable under worst case operating conditions to within ±1% for 2 hrs. Conditions to be considered in the worst case analysis are temperature, humidity, line voltage, and line frequency. A warmup period of 10 min will precede all testing.

3.4.11 Internal Diagnostics

A set of internal diagnostic functions will be provided. The intent of these diagnostics is to assess critical data and information paths, and to ensure satisfactory operation. A secondary purpose is to enable quick isolation of a problem. At a minimum, the internal diagnostic programs must isolate the problem to the instrument level. Additional diagnostics, which isolate the problem area to the module level, will be required if first echelon maintenance is to include module replacement. The internal diagnostic programs can be activated by either the system control, through the instrument bus, or via the operator. Status information will be returned to the initiator upon successful completion or failure.

The internal diagnostics will access the operation of at least 80% of the components in an active state. The dynamic test uses by the diagnostics include the typical anticipated operating condition of the instrument.

In the event of a failure, the appropriate error code will be logged in the nonvolatile memory for future reference. In the event that the instrument is configured of multiple modules, the error code will be logged in the nonvolatile memory of that module in error, as well as within the instrument main frame. A capacity to store at least 64 error conditions will be provided in each module and a capacity for 256 errors will reside in the main frame. Each time the instrument is powered up, the self-diagnosis will be executed.

3.4.12 Communication Protocol

The hardware requirements of the instrument bus are well defined in IEEE 488; however, the communication protocol of the bus is not. It is recommended that the system controller-instrument interchanger follow the procedure outlined in Appendix D.

The effective transmission rate over the instrument bus should exceed 30 kilobytes/second, including all software overhead in the system controller and the instrument.

3.4.13 Filter

The instrument will incorporate two digital filters, one for each output channel. The filters will have at least 10 coefficients when implemented in a nonrecursive structure. Optionally, the filters may be set up as recursive filters using three (3) cascaded second-order sections. When in the system controller mode, the filter parameters will be down loaded from the system controller. The appropriate parameters (coefficients) will cause the filter to act as a traditional low pass, high pass or band pass filter. In the manual mode the operator will choose the filter of interest via the equivalent analog type.

Although the filter implement is digital, the operator will not be required to input coefficients. His selection will be along the traditional lines for analog filter selection, i.e. band pass from 10 hz to 40 hz or low pass with a cutoff frequency of 40 hz.

3.4.14 Display

The instrument will have at least one CRT display with a minimum resolution of 256 × 256 pixals. The display may be either a bi-stable storage tube or a rastor scan refresh display, although a rastor display is preferred. In the event a rastor scan display is used, memory storage to refresh the display will at least equal 1 bit per pixal. If no other alpha numeric display is present on the instrument, the CRT display will double as such. An alpha numeric character density of 12 lines × 60 characters is required. The same display memory may be used for both alpha numeric and graphic displays. The display will have a minimum diagonal dimension of 12 cm (5 inches). Alternative displays, such as LCD or plasma display can be considered as replacements for the CRT; however, the specifications are subject to review and approval by the procuring authority.

3.4.15 Manual Mode and System Controller

The operator, through the front panel, and the system controller, through the instrument bus, will be able to modify the state of the display control parameters. All parameters listed in Table A-1, except the curser control and character output (8A and 8b), will be controllable from both the system controller and manual mode. The curser control and character output will be accessible only by the system controller.

3.4.16 Threshold Gate

A programmable gate will be included in the instrument. At a minimum, the gate will be able to define a rectangular area of acceptance using four programmable parameters (i.e. an upper and lower acceptance limit for each of the output channels). In addition the gate may be disabled or enabled by either operator and/or system controller. The relationship between the gate and the signals shown on the CRT will be maintained under all display conditions. When the instrument is in the system controller mode, the system controller will have the option to enable or disable an interrupt signal from the gate. A second means for polling the gate by the system controller will also be provided. A detailed list of gate control parameters is given in Table A-1, items 9 through 9i.

TABLE A-1. MANUAL/AUTOMATIC CONTROL FUNCTIONS

Function	Number of Minimum Description Levels	Range	Computer	Manual
1. Gain (Sensitivity)	1000	0-40 dB	Read/Write	Set/Read
2. Frequency	Programmable with selected to within 0.1%	500 kHz to 5 MHz in 500 kHz steps	Read/Write	Set/Read
3. X Balance	1000	Dependent on bridge design	Read/Write	Set/Read
4. R Balance	1000	Dependent on bridge design	Read/Write	Set/Read
5. Phase (Rotation)	1000	360 deg	Read/Write	Set/Read
6. Filter Parameters				
a. Coefficient 1	16 bits	±32K	Read/Write	Set/Read
b. Coefficient 2	"	"	"	"
c. Coefficient 3	"	"	"	"
d. Coefficient 4	"	"	"	"
e. Coefficient 5	"	"	"	"
f. Coefficient 6	"	"	"	"
g. Coefficient 7	"	"	"	"
h. Coefficient 8	"	"	"	"
i. Coefficient 9	"	"	"	"
j. Coefficient 10	16 bits	±32K	Read/Write	Set/Read
l. Enable/Disable	On/Off	0 or 1	Read/Write	Set/Read
7. Bridge Balance Control	On/Off	0 or 1	Read/Write	Set
Status	Satisfactory/Unsatisfactory	0 or 1	Read	N/A
8. Display Controls				
a. Gain X	10 bits	0/30 dB	Read/Write	Set/Read
b. Gain Y	10 bits	0/30 dB		
c. Offset X	10 bits	± 10 dB		
d. Offset Y	10 bits	± 10 dB	Read/Write	
e. Clear Screen	On/Off	0/1	Write	Set
f. Cursor Control	X, Y Position	ANSI Format	Read Write	N/A
g. Character Output	Full ASCI character set		Write Only	N/A

TABLE A-1. MANUAL/AUTOMATIC CONTROL FUNCTIONS (Continued)

Function	Number of Minimum Description Levels	Range	Computer	Manual
9. Internal Gate				
a. Min X		Display Range		
b. Min Y				
c. Max X				
d. Max Y				
e. Enable Gate Display	On/Off	0/1	Read/Write	Set/Read
f. Enable Gate	On/Off	0/1	Read/Write	Set/Read
g. Interrupt Enable	On/Off	0/1	Read/Write	N/A
h. Interrupt Status	On/Off	0/1	Read Only	N/A
i. Interrupt Rate	1000	0.001 to 10 sec	Read/Write	N/A
10. Instrument Status				
a. Serial No.	10 digits		Read Only	Read
b. Module Serial No.'s	10 digits		Read Only	Read
c. Module Serial No.'s	10 digits		Read Only	Read
d. Module Serial No.'s	10 digits		Read Only	Read
e. Module Serial No.'s	10 digits		Read Only	Read
f. Power Condition	*On/Off*	*0 or 1*	Read Only	N/A
g. Manual/Auto	On/Off	0 or 1	Read/Write	Read
h. Control/Disable	One bit/control	1 bit/control	Read/Write	N/A
i. Error Count	8 bits	0 to 256	Read Only	Read
j. Input Buffer Status	No. of bytes	0 to 256	Read Only	N/A
k. Output Buffer Status	No. of bytes	0 to 256	Read Only	N/A
l. Read Error Conditions to Output Buffer		Enable/Disable	Read/Write	N/A
m. Initiate Self-Test and Status		Enable/Disable	Read/Write	Set/Read
n. Self-Test Error Codes		Enable/Disable	Read Only	Read
11. Pause Command	"Halts internal instrument processor until a resume command is given (all functions are halted except communications)			
12. Resume Command	Inverse of pause			

3.4.17 Special Instrument Status and Control

In addition to the requirements for automatic response to serial number requests mentioned previously, other instrument state information must be available (Table A-1, items 10 through 10n) to the control processor. The intent of this status and control function is to allow for maximum flexibility and minimize misinterpretation. For example, the ability to selectively disable and enable manual control of the instrument function limits the possibility that a state of the instrument has been changed by the operator without system controller knowledge, yet it allows that option where necessary.

3.5 Finish — Color

The finish and color of the equipment enclosure will be that normally supplied by the manufacturer.

3.6 Design and Construction

3.6.1 Design

The eddy current equipment will be designed with the intention of providing an instrument of high reliability and stability. Attention must be directed toward human factors to assure that the equipment can be accurately standardized for all examinations by providing clearly marked controls and simplification of their adjustment. The cathode ray tube will provide a bright image that enables the operator to observe indications clearly under all ambient lighting conditions. Each system will be inherently designed to provide and maintain reproducible test results, in accordance to the testing requirements of Paragraph 4, when produced in production quantities.

3.6.2 Construction

Provisions will be made to ensure that electrical connectors are mated only to the appropriate counterpart. Where design considerations require close proximity of connectors of similar configuration, mating connectors will be suitably and permanently marked or coded.

The design and construction will include built-in adjustments or compensating devices for restoring the equipment to the specified tolerances. These devices will be capable of compensating for the change in performance that is expected to occur over a minimum period of one year (shelf time plus usage).

All modules will be connected with plug type connectors to minimize fretting and corrosion, which might lead to possible failure or create high resistance paths. Card edge connectors are acceptable as an electrical connection, provided the appropriate protective plating is applied and a rigid support system is used to ensure the cards will not become loose.

All analog circuitry will be constructed on double-sided, through-hole plated-printed circuit boards and solder mask coatings will be applied. Digital construction will be wire-wrapped on printed circuit board in accordance with the manufacturer's option for prototype instruments. Production instruments will be double sided with plated-through holes. All digital circuit boards must be operable with extender cables or boards. The contractor will supply the required extender cables or boards with each instrument. The cables or boards will be of sufficient length to effectively diagnose a problem.

3.6.2.1 *Test Points*

Test points will be provided in the form of terminal posts that are accessible for evaluation of the circuit while the instrument is operational and the covers are removed. Test points will be identified on the layout and circuit schematic and on the chassis or circuit board where they are located. The choice of test points will be made by the instrument manufacturer/designer such that a problem can be isolated to the board level. Additional test points will also be provided where a signal must be measured for calibration or adjustment of the instrument.

3.6.3 Controls, Indicators, and Readouts

Primary controls used for adjusting the equipment for examination or conducting examinations will be located within sight and easy reach of the operator. All primary controls will be located on the front panels. Secondary controls used infrequently to calibrate the electronics or adjust the display should be located within the enclosure or in an area less accessible to the operator. Each control used to adjust the instrument for examinations will be clearly and legibly marked with regard to function and values of adjustment.

Nomenclature will be in accordance with descriptive terms used in this specification. Nomenclature and graphics selected will be submitted for approval by the procuring activity.

3.6.4 Cooling

The equipment will be capable of being operated continuously for 24 hr at maximum ambient temperatures described in this specification with ac power. Forced cooling, if required, will be performed by an air exchanging device with appropriate filters to eliminate the potential intake of dust and other airborne particulates.

3.7 Marking and Identification

Marking of equipment for identification will be in accordance with MIL-T-28800B, Section 3.8.3 for Type III equipment. Front panel markings will be those conventionally used for each function or an abbreviation thereof. The marking process used will be permanent and legible from 1 m (39.37 in.) under lighting conditions of 15-ft candles (160 1X). Panel markings will have the durability to meet the marking test described in MIL-T-28800B, Section 4.5.7.6.

Identification and supplemental plates may be located on the rear panel of the instrument. The instrument identification plate will contain the following information:

- Model Number and Revision (internal programming version provision)
- Equipment Name or Description
- Serial Number
- Power Requirements
- Manufacturer's Name

Probes will be identified as follows:

- Model Number
- Description (3/8" dia bolthole, probe, etc.)
- Serial Number
- Manufacturer's Name

Cables and other accessories will be labeled in an appropriate manner that permits identification (model, voltage, length, etc.) for reporting, inventory, and ordering purposes.

Warning markings will warn of the location of a hazard, its nature and extent in accordance with MIL-T-28800B, Paragraph 3.8.3.1.2 and 3.8.

In addition to the external markings, the instrument will respond with its own internal electronic identification codes as outlined in Table A-1.

3.8 Environmental Requirements

Equipment will meet the requirements of Section 3.9, MIL-T-28800B for class equipment except as specified.

- Equipment warm-up per paragraph 3.9.1.1 will not exceed 10 min. at ambient conditions.
- Equipment will have a low temperature operating range of 0°C (32°F) vs −15°C (5°F) specified in Table A-2, Section 3.9 and 50°C.
- The environmental requirements will be restricted to humidity, low temperature, high temperature, and power fluctuation (voltage and frequency).

3.8.3 Electromagnetic Capability

The equipment will be equipped with a suitable magnetic shield to ensure that the electronic beam in the cathode ray tube is sufficiently shielded from the effects of magnetic fields that may occur in industrial environments.

Electromagnetic interference will be minimized by appropriate grounding and isolation so that at full instrument gain the interference from internal timing signals, relay action, and other external electronic radio frequency noise common to industrial activity is not more that 1% of full screen deflection with the receiver input connected to a standard probe.

3.9 Interchangeability

Major components of the system, such as the programmer, bridge, filter display gates, probes, etc., supplied by each manufacturer, will be interchangeable. Both mechanical and electrical aspects of the eddy current equipment will afford this interchangeability. Interchangeability can be either at the board level or at the module level.

3.10 Documentation

3.10.1 Operation and Service Manuals

An instruction manual described in Data Item Description M-5120, Instructions 1 through 5, and other additional information required for field use of this equipment will be developed by the contractor.

A manual addressing the maintenance of this equipment as well as the operation and necessary instructions for initial setup will be provided in accordance with the requirements of Data Item Description M-5120, "Instruction Manual -- Minimum Specification Requirements." Style will be in accordance with MIL-M-38784A. A bound copy suitable for a

six-month field trial of equipment will be provided with each set of equipment ordered. One original unbound copy draft, final copy and set of reproducible illustration originals are required in addition to bound copies per items 3, 4, and 5 of M-5120.

3.10.2 Use of Metric/English Units

All component dimensions illustrated in drawing will be provided in metric (SI) units followed by English units in parentheses for those commonly reported in English units.

3.10.3 Glossary

A glossary of terms will be established by the contractor for the purposes of identifying controls, writing the operator and maintenance manual and labeling equipment. The glossary will be submitted to the purchaser for review and approval to assure that "standard" nomenclature is established prior to the supplier's use of these names and abbreviations.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection and Test

Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified, the supplier may use his own facilities, or any commercial laboratory acceptable to the Procuring Activity. The Procuring Activity reserves the right to witness or perform any of the inspections set forth in these specifications where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Quality Program

The contractor will provide and maintain a Quality Program which as a minimum includes the following:

4.2.1 Inspection System

An inspection system in accordance with MIL-I-45208;

4.2.2 Initial Quality Planning

The contractor, during the earliest practical phase of the contract, will conduct a review of the requirements of the contract to identify and make timely provison for special controls, processes, test equipment, fixtures, tooling, and skills required for assuring product quality. This initial planning will recognize the need to prepare and update inspection/test procedures and techniques, and to procure required equipment and services as well as interfacing these quality controls with manufacturing procedures. The planning will also provide appropriate review and action to assure compatibility of maufacturing, inspection, testing, and documentation.

4.2.3 Design, Drawing, and Configuration Controls

A design review meeting involving both the contractor and the procuring activity will be held prior to fabrication of any units. The contractor will notify the procuring activity at least 30 days in advance of the time and place of the design review meeting.

The contractor will establish procedures to assure timely incorporation and control of the configuration. These procedures will include:

a. Control of document transmittals (e.g., drawings, specifications, work instructions, etc.) to all affected organizations (including suppliers and subcontractors) to assure that work and quality functions are accomplished in accordance with the latest approved documents and that obsolete documents are removed from use.

b. Verification that the "as-built" configuration conforms to applicable specifications, drawings, and other contractual requirements including all authorized changes and modifications and that the affected documents are revised to accurately describe the "as-built" configuration.

4.3 Tolerances

Tolerances on specified performance parameters and physical dimensions will be as indicated. Where no tolerances are shown, a nominal value is implied and a tolerance of ±5% will be applicable.

4.4 Inspection Terms

Military Standard MIL-STD-109 will govern the definition of inspection terms used.

4.5 Inspection and Test Requirements

Each eddy current equipment item will be inspected and tested as a completed article. The contractor will develop the procedure necessary to provide objective evidence that the requirement has been met. These procedures will be included in the overall test procedure plan (see Paragraph 4.6).

4.5.1 Test Conditions

Unless otherwise specified herein, tests will be conducted at the ambient temperature and climatic conditions existing at the place of test. Only that maintenance established prior to the tests and submitted as a maintenance schedule prior to commencement of the tests will be performed during the tests.

4.6 Test Procedure Plan

The procedures used for conducting First Article Tests will be prepared by the contractor and submitted to the Procuring Activity for acceptance at least 30 days prior to the scheduled date of test. The Procuring Activity review period will not exceed 30 days. The Procuring Activity or their representative reserves the right to modify the tests or require any additional tests deemed necessary to determine compliance with the requirements of this specification. MIL-T-18303 should be used as a guide for preparation of such test procedures.

4.7 First Article Test Report

Test data will be recorded during performance of all First Article Tests in a form that will permit reference to the first article procedures and equipment used and will provide for actual readings, such as frequency, voltage, time, dimensions, etc., rather than check marks. This data will be incorporated in a First Article Test Report prepared and submitted within 30 days after completion of First Article Tests. MIL-STD-831 should be used as a guide for preparation of this test report.

4.8 Reliability and Maintainability

4.8.1 Reliability

This eddy current instrument will have a lower tested limit on mean-time-between-failure (MTBF) of 1000 hr as defined in MIL-STD-781C when tested and accepted in accordance with the provisions of Section 4 and 6 of specification GSED PD 94.

4.8.2 Maintainability

The instrument will have a corrective meantime-to-repair at an intermediate depot of 1 hr as defined in MIL-STD-471A.

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX B
ULTRASONIC TEST INSTRUMENTATION SPECIFICATION

Prepared by:

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APPENDIX B

ULTRASONIC TEST INSTRUMENTATION SPECIFICATION

1.0 SCOPE

This specification established the minimum performance and design characteristics for ultrasonic equipment to be used as a computerized immersion ultrasonic module in a Retirement for Cause (RFC) system for the nondestructive inspection and evaluation of used jet engine major rotating parts. The equipment will be suitable for use in United States Air Force (USAF) depots, and includes necessary transducers, spares, cables, and ancillary equipment as specified herein.

2.0 APPLICABLE DOCUMENTS

The following documents of the issue in effect on the date of the invitation for bids or request for proposal form a part of this specification to the extent specified herein.

2.1 Government Documents

2.1.1 Specifications

MIL-T-28800B	Test Equipment for Use with Electrical and Electronic Equipment, General Specification for
MIL-I-45208	Inspection System Requirements
MIL-M-38784	Manuals Technical; General Style and Format Requirements
MIL-T-18303	Test Procedures, Reproduction, Acceptance and Life for Aircraft Electronic Equipment, Format for

2.1.2 Standards

MIL-STD-810	Environmental Test Methods
MIL-STD-831	Test Reports, Preparation of
MIL-STD-109	Quality Assurance Terms and Definitions
MIL-STD-794	Packaging

2.1.3 Other Publications

DI-M-5120	Instruction Manual - Minimum Specification Requirements

2.2 Nongovernment Documents

ANSI/IEEE Std. 488* IEEE Standard Digital Interface for Programmable Intrumentation

ASTM t.07.06.09-75-2-7 Recommended Practice for Evaluating the Electronic Characteristics of Sections of Pulse Echo Ultrasonic Inspection Instruments (Proposed)

ASTM E127-75* Recommended Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks

ASTM 3500 - 74* Standard Definitions of Terms Relating to Ultrasonic Testing

Specification BNW 705-7, AFML Project 705-7, USAF Contract F33615-78-C-5032

UL 1410* Standard for Television Receivers and Video Products

IEEE Std. 100* "IEEE Standard Dictionary of Electrical and Electronic Terms"

2.3 Document Sources

Copies of Specifications and Standards and other publications referenced in this specification except for those indicated (*) may be obtained from the procuring activity.

3.0 REQUIREMENTS

3.1 General Requirements

The equipment will be designed for use in a depot environment by engineers and trained technicians. It will be suitable for use in immersion testing, both pulse-echo and through transmission (possibly including the simultaneous use of three transducers). It will be capable of bidirectional communication with a computer, as well as providing convenient manual control and visual display.

The frequencies of operation range from 1.0 MHz through 25.0 MHz. The primary purpose of the instrument will be the detection of internal penny-shaped flaws of diameter 0.015 inch (0.38 mm) and larger, in jet engine disks composed of nickel and titanium based alloys.

The equipment will be designed and manufactured in a manner that will result in commercially reproducible equipment. The equipment will afford a high degree of test repeatability, from unit to unit and from module to module.

3.2 Safety

With the exception of radiation energy measurement, this equipment will incorporate the safety features of MIL-T-28800B, Paragraph 3.2. It will meet the appliance shock hazard test requirements of UL 1410, sections 12 and 13.

3.3 Equipment Description

The major components of each system will consist of the following items (Figure B-1).

3.3.1 Ultrasonic Instrument

(See Figure B-2.)

3.3.2 Signal acquisition and digitizing instrumentation (Figure B-3). Only one is required for several ultrasonic instruments.

3.3.3 Ultrasonic transducers, three of each type: (All are high damped. Note: These requirements may be changed per forthcoming Manufacturing Technology program for RFC).

5 MHz, 0.5 in. diam., 3 in. focus

10 MHz, 0.375 in. diam., 3 in. focus

10 MHz, 0.375 in. × 2.7 in. receiver, unfocused

20 MHz, 0.375 in. diam., 3 in. focus

3.3.4 Power Cord, 2 each (one for Ultrasonic Instrument, one for Waveform Digitizer).

3.3.5 Coaxial cables, 6 each, 50 ohm, BNC to transducer holder or search tube connector, 6 feet.

3.3.6 Spare modules for both Ultrasonic Instrument and Waveform Digitizer.

3.3.7 Data communications cable, per IEEE 488, length to reach external controller, 2 each (one for Ultrasonic Instrument and one for Waveform Digitizer).

3.3.8 Acoustic verification fixture.

3.3.9 Extender modules and cables, as required for repair procedures (both Ultrasonic Instrument and Waveforem Digitizer).

3.3.10 Instruction and Operating Manual (per DI-M-5120).

3.3.11 Installation and Maintenance Manual, including schematics (per MIL-M-38784).

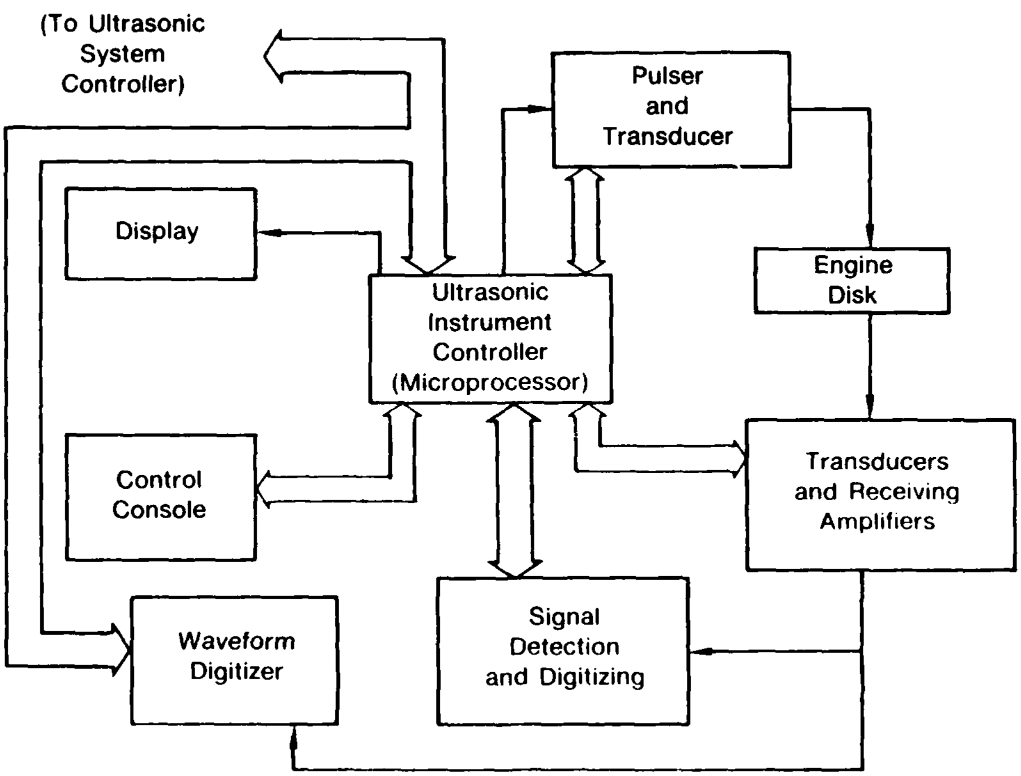

Figure B-1. Major Ultrasonic Test Instrumentation System Components

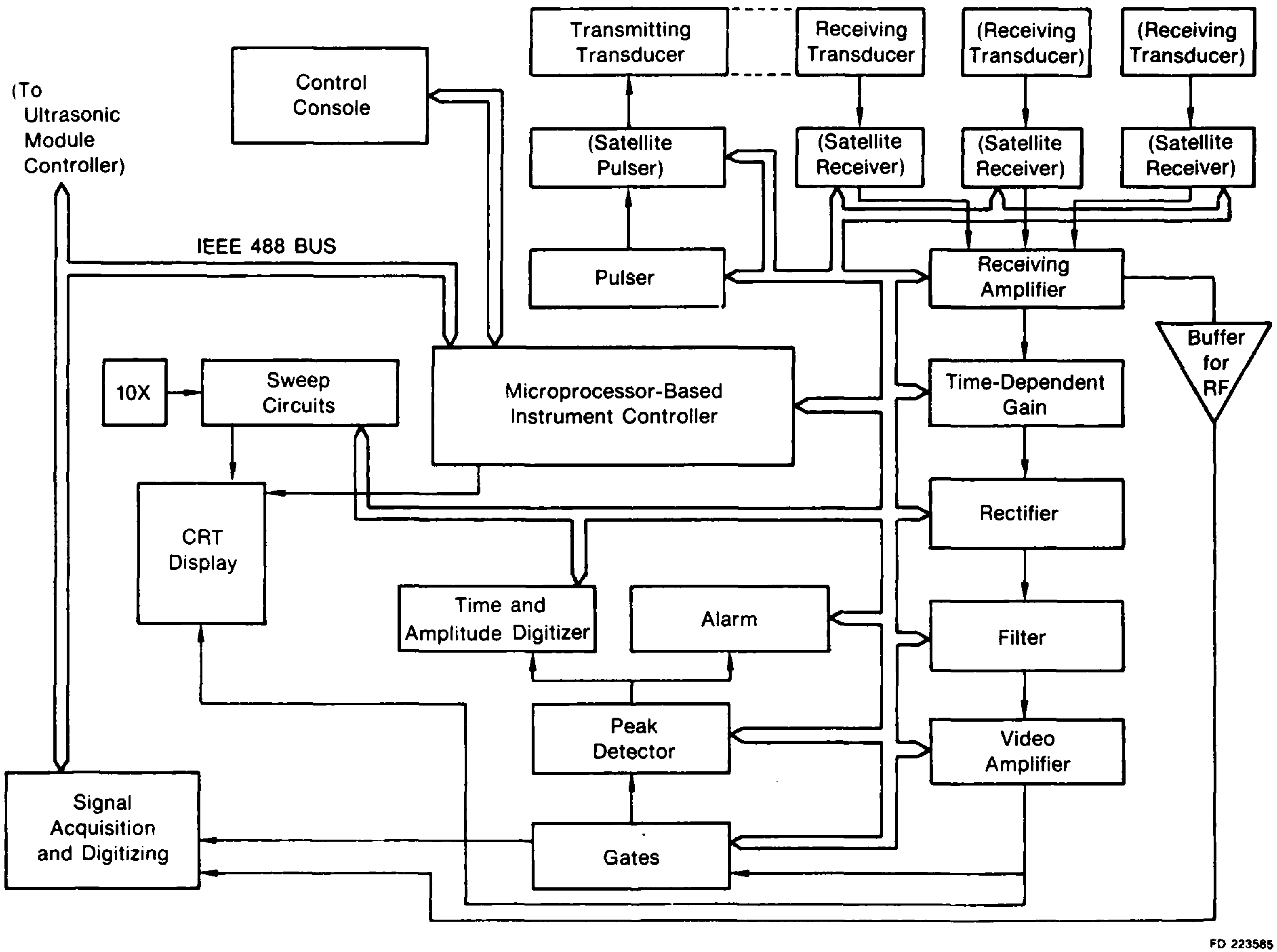

Figure B-2. Ultrasonic Instrument Schematic

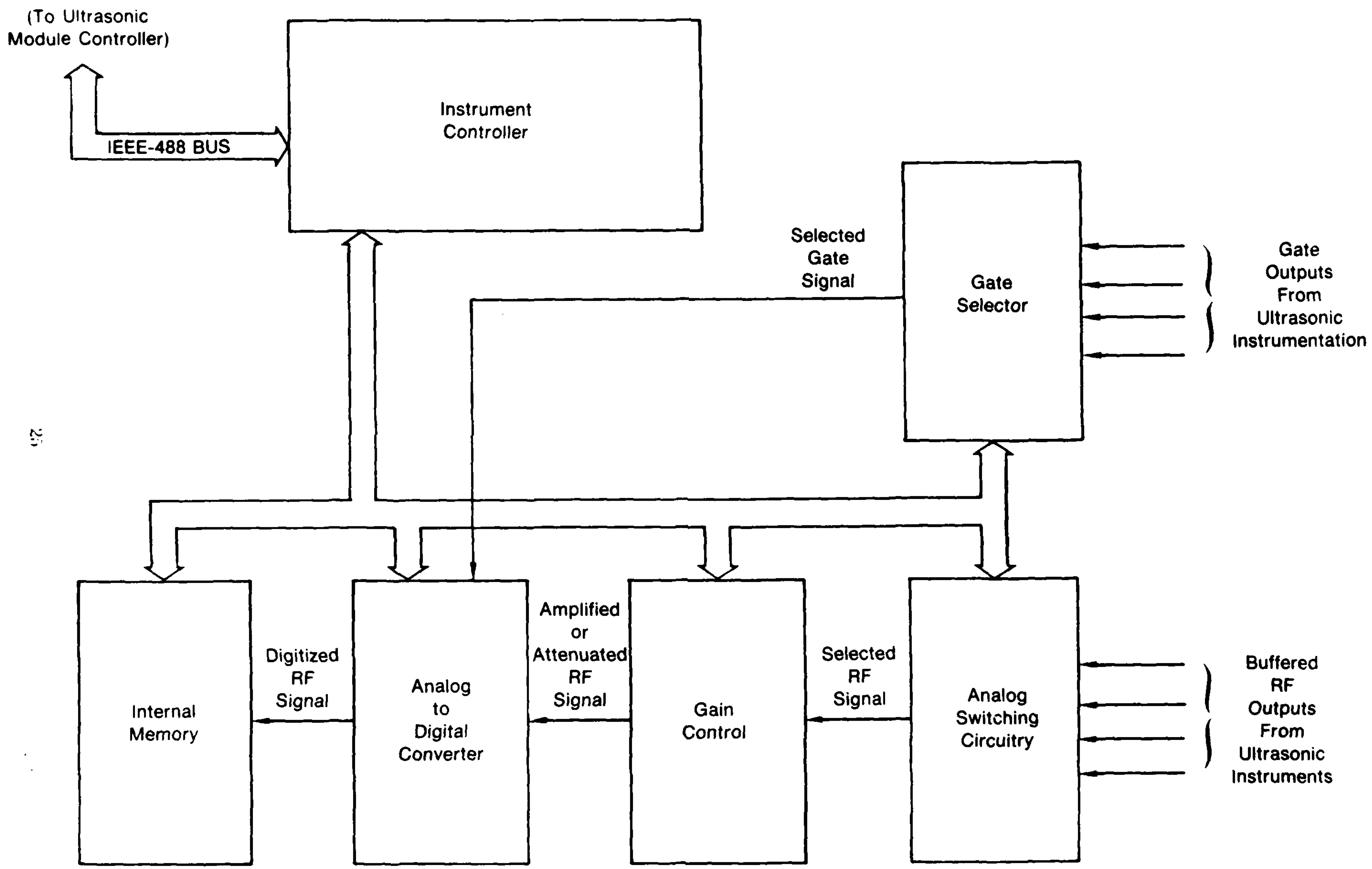

Figure B-3. Signal Acquisition and Digitizing Instrumentation

3.4 Detailed Equipment Specification

3.4.1 Instrument Description

The instrument will be capable of both manual and externally controlled operation. The functional block diagram is shown in Figures B-1 and B-2. The instrument will be so constructed as to allow rapid repair by submodule and/or component replacement.

The linear dynamic range of the instrument will be at least 34 dB at maximum gain when tested in accordance with Appendix VI of Specification BNW 705-7.

The operating environment temperature range of this instrument will be 50°F (10°C) to 120°F (50°C). The humidity range for operation and storage will be 0% to 95% noncondensing.

All ultrasonic signal connectors will be BNC type, 50 ohms; all analog cable (including search tube, if used for signal routing) will be 50 ohms. The external controller connector will satisfy ANSI/IEEE Standard 488. Other connectors will satisfy applicable Mil specs.

3.4.2 Instrument Control

All instrument functions, unless otherwise specified, will be controllable both via manual (front-panel) control, and via remote (UT module computer) control. The instrument will include an internal industry-standard microprocessor with both read-only memory (ROM, PROM, or EPROM) and dynamically alterable random-acess memory (RAM). The interaction between manual and remote control will be such that (1) the operator can independently set all controls; (2) the UT module controller can independently set all controls; (3) the operator can determine the values of all remote control settings; (4) the UT module controller can determine the values of all operator settings; (5) when "remote" mode is specified, the operator controls are inoperative; (6) the operator can readily set all manual settings equal to the remote settings in order to make selected changes from those settings. The instrument will provide a facility for making temporary settings, so that the operator can select a set of baseline control settings, vary certain settings, and return to the baseline. This facility may be accomplished via instrument interaction with the UT module controller; however, the operator will use only front-panel controls.

The front-panel controls need not be physically on the front of the instrument; rather, they may be incorporated with the UT bridge and/or UT module computer controls. In any case, the operator will be able to operate both bridge and instrument manual controls from a single position, for set-up and evaluation purposes.

Although the RFC system is designed for completely automatic operation, the use of manual controls is necessary during the initial methods development (or "machine training") stage. This training process will be carried out by interaction between an ultrasonic engineer and the computerized system, and thus requires convenient, effectual control by the human as well as by the computer. The training will be required for each new inspection requirement on each new part introduced into the RFC system, and will therefore be a continuing process.

3.4.2.1 Operation of Manual Controls

Each manual control will permit setting to any value within 5 seconds. Each control will also permit continuous adjustment throughout its full range at both a fast and slow rate. If digital control is used, the rates will be selectable to permit accurate fine adjustment at the lowest rate. The slow rate will be approximately one-tenth of the highest rate. Level setting of each control will be unaffected by turning the control on and off. Operator control settings will

not be altered by cycling the instrument on and off. Operator controls will be labeled, shaped, colored, and arranged to provide ease of operation for engineers who do not use the instrument daily, as well as for trained regular operators.

3.4.2.2 Operation of Remote Controls

Each control will be settable to any value within one instrument cycle (i.e., control will be accomplished at a rate at least equal to the instrument repetition rate).

3.4.2.3 Specific Controls

The following controls will be provided:

3.4.2.3.1. Repetition Rate

- Rate
- Local/remote

3.4.2.3.2 Pulser

- Transducer frequency (controls pulse duration and peak voltage)
- Damping resistance

3.4.2.3.3 Receivers

- Gain
- Time-dependent gain
- Filter

3.4.2.3.4 Detector

- Full-wave, half-wave-positive, half-wave-negative

3.4.2.3.5 Video Processors

- Video filter

3.4.2.3.6 Gates

- On/off
- Synchronization
- Start time
- Duration
- Threshold
- Alarm polarity
- Audio on/off
- Interface attenuation on/off
- Interface attenuation level

3.4.2.3.7 Display (require manual control only)

- Sweep speed
- Sweep synchronization
- Sweep delay
- Setup/normal
- CRT controls (vertical and horizontal positions, intensity, focus, and astigmatism)
- Sweep expansion on/off

3.4.2.3.8 Power On/Off (requires manual control only)

3.4.2.3.9 Begin self-test.

3.4.3 Repetition Rate Circuit

A clock circuit will provide the general timing and circuit synchronization. The repetition rate will be variable from 100 Hz to 5 KHz in increments of 10 Hz. Moreover, the instrument will provide a mode in which each pulse repetition is initiated by a command from the UT module controller.

The upper limit of 5 kHz is sufficient to inspect with a 0.015 in. resolution at a 20 in. radius at 30 rpm. The lower limit is low enough to prevent "ghosting" (reverberations continuing from one instrument cycle to the next). The 10 Hz increment will allow rep rate to be synchronized with rotation speed and inspection radius for the highest possible inspection speed. External pulse initiation allows complete flexibility during training and evaluation.

3.4.4 Pulser

The excitation pulse generating circuit will provide requisite circuitry and controls to drive piezoelectric transducers having nominal frequencies between 1.0 MHz and 25.0 MHz. Variable pulse width allows maximum energy transfer to the transducer. Pulser characteristics will include at least the following:

Nominal Frequency (MHz)	*Pulse Duration (ns)*	*Peak Voltage (V)*	*Transducer Diameter (in.)*
1.0	500	−250 to −600	0.50-1.00
2.25	220	−250 to −500	0.25-0.75
3.5	145	−250 to −400	0.25-0.50
5.0	100	−300 ± 50	0.25-0.50
7.5	65	−300 ± 50	0.25-0.50
10.0	50	−300 ± 50	0.25-0.375
15.0	30	−250 ± 50	0.25-0.375
20.0	25	−200 ± 50	0.25-0.375
25.0	20	−200 ± 50	0.25-0.375

Peak voltage will be measured across an undamped lead metaniobate piezoelectric element of the specified frequency and diameter. If continuous frequency variation is provided, characteristics at intermediate frquencies will be as interpolated from those given. Lower voltages are specified at higher frequencies to prevent damage to the transducer due to arcing in the thin element.

The pulser will provide variable or selectable damping resistance in parallel with the output, to include at least the following values: 10 ohms, 50 ohms, 100 ohms, and 1000 ohms. Variable damping permits optimization of ultrasonic wave shape.

The pulser will have a switch to permit the pulser to be isolated from the receiver for transmit-receive operation or connected to a common output for pulse-echo operation. When in the transmit-receive mode, there will be a minimum of 60 dB isolation of the pulse output and other timing signals from the receiver input.

If the system configuration is such that the UT instrument is not mounted on the bridge, then the pulser will be physically external to the instrument and will be mounted on the bridge. Mounting the pulser on the bridge minimizes cable losses and distortion. Ideally, the pulser should be adjacent to the transducer, as specified in Section 3.4.20, Enhancements.

3.4.5 Self-Test Capabilities

Inspection reliability requires three types of calibration: instrument calibration, system calibration, and system setup. System setup consists of setting controls to achieve required responses from test blocks specific to an inspection; this is a system function. System calibration is a detailed analysis of system (transducer and instrument) response to a special calibration block; this is also a system function. Instrument calibration consists of signal checking within the instrument. Initial and periodic calibrations must be performed by an electronic technician; however, periodic self-testing by the instrument is also required.

Upon computer or operator command, the instrument will be capable of performing self-tests to verify proper operation (or isolate improper operation, at least to modular level, and preferably to functional level) of all controls and signal processing circuits. If the test commences by verifying proper communication with the UT module computer, then the remainder of the test may be interactive with the UT module computer. The test will provide a calibrated signal or set of signals into some stage of the receiver, adequate to allow determination of correct or incorrect functioning of any portion of the instrument. The self-test need not be redundant with tests that can reasonably be carried out using the transducer and tank, but rather the self-test is intended to (1) assure whether transducer-tank tests can be carried out, and (2) aid in troubleshooting if the system is malfunctioning to the extent that transducer-tank tests cannot be performed.

3.4.6 Resolution

The instrument will be capable of detecting a 0.015 in. (0.38 mm) diameter flat reflector located 0.030 in. (0.76 mm) below the surface of a test block. The 0.030 in. resolution fills the gap between eddy current and conventional ultrasonic inspection. "Baseline resolution" (visual separation, to the baseline, of front-surface and echo signals) is not required; however, reliable and repeatable detection must be demonstrated, under automatic setup conditons.

3.4.7 Receiver

3.4.7.1 General Requirements

The receiver will be a broadband design having a frequency response with −3 dB points at 1.0 MHz or less and 30.0 MHz or greater, and an input impedance of 50 ohms. The 30 MHz bandwidth is sufficient for 0.030 in. resolution. A higher bandwidth would begin to run into attenuation limits in water and disk material. The receiver noise referenced to the input will be no more than 30 microvolts rms in broadband mode, and 15 microvolts rms in tuned modes, when measured in accordance with Appendix V of Specification BNW 705-7. The receiver

maximum gain will be at least sufficient to provide full-screen deflection for 30 microvolt input. It will have a linear dynamic range of at least 36 dB at all gain settings when tested in accordance with Appendix VI of Specification BNW 705-7.

3.4.7.2 Gain

The receiver gain will be adjustable in 1 dB steps over the full range of 0.80 dB. Overall accuracy will be ±1.5 dB over the full range. Relative accuracy between all pairs of settings will be between 0.8 and 1.2 (see below).

The overall gain of 80 dB is adequate to permit analysis of unsaturated signals, from the high-frequency noise level through a low-frequency flat plate reflection. The 1 dB step size, combined with a 5% gate level adjustment, permits gating and analysis at any required level. The absolute and relative accuracies are sufficient to permit repeatable measurements, yet achievable with current technologies. Higher accuracies would not enhance the system, as mechanical and acoustical limitations intervene.

Relative accuracy of two gain settings means the ratio Dn/Da, where Dn is the nominal difference between the two gain settings and Da is the actual difference between the receiver gains at those settings. (The intent of this requirement is to preclude, for example, a nominal gain of 31 having an actual gain of 32, with a nominal gain of 32 having an actual gain of 31, which is permitted by the ±1.5 dB overall requirement.

3.4.7.3 Avoiding Saturation

Circuitry will be provided at the receiver input to supress the transmit or excitation pulse to minimize overdriving the amplifier when used in the pulse-echo mode and afford the specified resolution capability. If any amplification stage becomes saturated, then all successive stages will be working with a saturated signal, which no longer bears a linear relationship to the received rf signal from the transducer. If the signal is saturated at all stages, this is no problem; however, if a later stage displays, say, an 80% signal out in response to a saturated signal in, then all instrument outputs above 80% become suspect. To prevent nonlinear operation, the receiver will be designed to saturate first at the final stage of amplification, at all gain settings (in other words, only an "off-screen," or out-of-range, signal can be caused by saturation; signal clipping at lower amplitudes cannot occur); this criterion will apply also to the attenuated backface signal monitored by the backface gate. In the case of the backface signal, in which the instrument gain is raised by time-dependent gain, it is important that the back-echo attenuation be performed before (or as part of), but not after, the time-controlled gain; or a separate amplification and detecting circuit may be used for the back-echo gate.

3.4.7.4 Buffered Rf

A buffered rf signal from the final stage of amplification, having equivalent frequency response and linear dynamic range as the receiver, will be provided on an externally accessible BNC connector; output impedance will be 50 ohms. This is required for input to the Signal Acquisition and Digitizing Instrumentation. At maximum gain, a 30 microvolt input to the receiver will result in at least an 0.1 volt output.

3.4.7.5 Time-Dependent Gain

The receiver will provide time-dependent gain and back-echo attenuation. The purpose of the time-dependent gain will be to compensate for attenuation, beam spread, and front-surface effects. The feature will vary the gain by up to 2.5 dB per microsecond

(equivalent to 20 dB/in. roundtrip in highly attenuative powder metal), variable in at least four sequential, separately controllable exponential segments or eight sequential linear segments. The length of each segment will be adjustable in increments of 0.1 microseconds or less. The minimum length of the first segment will be 0.3 microseconds or less. The minimum length of all other segments will be 1.0 microseconds or less. The maximum length of each segment will be 12.0 microseconds or greater. The first segment will be capable of reverse compensation (positive gain slope, with near-surface gain greater than gain at depth) to compensate for front-surface effects.

3.4.8 Video Processor

The video processor will convert rf signals, in the frequency range 1.0 to 30.0 MHz, to rectified signals and will have a bandwidth with −3 dB points at 1 MHz or less and 50 MHz or greater. The rectification mode will be selectable among full-wave, half-wave-positive, and half-wave-negative. Using a tone burst, the rectified peaks of the detected, unfiltered signal will be balanced within 10% for all frequencies. The linear dynamic range will have the same requirements as the receiver.

3.4.9 Video and Vertical Amplifier

A video and vertical amplifier section will be provided for presenting the signals, gate positions, and alarm thresholds on the cathode ray tube. The video and vertical amplifier section will have a frequency response sufficient to display 25 MHz rectified signals: specifically, −3 dB points at 1.0 MHz or less and 30.0 MHz or greater. It will have a linear dynamic range meeting the same requirements as the receiver. As a minimum requirement, the gain of the video and vertical amplifier section will be sufficient to compensate for losses in the video processing network.

3.4.10 Sweep Circuits

The sweep circuit will provide selectable sweep speeds from 0.1 microseconds per centimeter through 0.2 milliseconds per centimeter. Sweep speed increments will be a 1, 2, 5 sequence or finer. A control (which need not be remotely controllable) will provide 10X expansion at each sweep speed. The expansion will be centered at the center of the horizontal sweep, adjustable manually in 0.01 microsecond increments at the highest sweep speed. A visual indication will alert the operator when the 10X expansion is in effect. Sweep speeds will be within 1% of nominal values. The low sweep speed enables detection and visualization of distant objects in the tank. The highest speed enables visualization of high-frequency transducer waveforms.

3.4.11 Sweep Delay

A sweep delay will provide a delay of up to 1.5 milliseconds before the start of the sweep, adjustable in increments of 0.05 microseconds or less. The beginning of the delay will be selectable to any of the following: initial pulse, interface signal, or beginning of any gate. The delay circuitry will also include a hold-off delay, which will prevent the detection of an interface signal from occurring earlier than the selected hold-off period. The hold-off delay will be synchronized to the initial pulse, and will be adjustable to the same requirements as the delay.

3.4.12 Display

The UT instrument will have a CRT with a viewing area at least 4 in. square. The display is required primarily for engineering use in methods development and "training" the computer system. It is also useful as a visual indication that the equipment is functioning properly. The

brightness of the display will be automatically regulated to provide comfortable viewing at high sweep speeds and low enough intensity at low sweep speeds to avoid damage or premature failure in the CRT. The display will be visible with a viewing hood at 200 Hz rep rate and 0.01 microseconds per centimeter sweep rate, and without a hood at sweep speeds of 0.1 microseconds per centimeter or slower. Manual controls will be provided for intensity, focus, astigmatism and horizontal and vertical positioning.

3.4.13 Signal Gates

Each receiver will have a set of four signal gates: one will provide indication of presence/loss of front face signal, one will provide 0 dB to 40 dB of attenuation for back-face monitoring, and two will provide signal monitoring for flaws. Each gate position will be indicated by a "pedestal" on the baseline. Each gate threshold level except the front face gate will be indicated by a horizontal display at the threshold level, directly above the associated pedestal, and approximately equal in length to the pedestal. The gate displays will turn on and off when the gate is turned on and off. The gates are the heart of the automatic ultrasonic inspection. The visual displays are for methods development and for verification of proper operation. The requirement for starting one gate immediately after a previous gate is primarily intended for the first gate to follow the front-face as closely as possible, to ensure 0.030 in. resolution. Two internal gates are required, to allow gating out of internal reflections without a time-consuming double zone inspection. The backface gate enables detection of flaws which interrupt the sound beam but do not reflect sound back towards the transducer. Delay values are sufficient to allow calibration and feature detection at large water paths. Delay increments are fine enough to allow accurate positioning of gates.

3.4.13.1 Gate Position (Start Time)

The gate positions will be controllable independently as to synchronization and delay. All gates will be capable synchronization to either initial pulse or front-face signal. The delay of the front-face gate start will be variable from 0.5 microseconds to 1500 microseconds, in increments of 0.5 microseconds or less, accurate to 0.05 microseconds. The other gate delays will be variable from 0.05 microseconds or less, and will be capable of synchronization to the trailing edge of any gate. The minimum delays specified are for actual values. Actual values of delays will be within 0.01 microseconds of nominal values (0.1 microseconds for front-face gate). All gates except the front-face gate will be capable of starting within 0.01 microseconds of the end of any other gate (e.g., by a pretrigger synchronization).

3.4.13.2 Gate Length (Duration)

The length of each gate will be adjustable to the same specifications as the position, except that synchronization of length will always be with respect to the start of the gate.

3.4.13.3 Threshold Level

The alarm level threshold of each gate will be adjustable from 5% to 100% of full screen (% F.S.) in increments of 5% F.S. or less. The threshold level will correspond within 2% F.S. to the signal amplitude level: for example, if the threshold is set to 36% F.S., then it will discriminate between signals less than 34% F.S. and signals greater than 38% F.S.; signals between 34% and 38% might cause sporadic triggering of the alarm.

The threshold level must be accurately specified in order to ensure repeatable inspections. A 5% increment, in conjunction with the 1 dB gain adjustment, is both adequate and achievable. The repeatability of high-speed peak detectors is inadequate for tighter tolerances than those specified.

3.4.13.4 Alarm

The alarm will be selectable between positive polarity (triggers when signal amplitude is greater than threshold) and negative polarity. It will be selectable to trigger after one to five successive instrument repetitions during which a signal goes above (positive) or below (negative) the threshold. The alarm will provide a signal capable of causing an interrupt and flag to the UT system controller.

The instrument will provide a two-tone audible alarm. One tone will sound momentarily when the alarm turns on and the other when the alarm turns off. The audible alarm will be enabled and disabled under manual control only.

The audible alarm is used only for setup and methods development. The usual audible alarm is unsatisfactory because in order to be heard, it must be so loud as to be irritating. A momentary alarm, with two tones to allow the engineer to distinguish between the signal's coming into the gate (or above the threshold) and leaving the gate (or dropping below the threshold) overcomes this problem.

3.4.14 Digital Output

All digital interchange with the UT controller and other instrumentation shall be via IEEE 488 bus. In addition to the instrument control functions (described under Section 3.4.2, Instrument Control), the following information will be provided by the instrument to the UT controller: gated signal information and alarm information.

3.4.14.1 Gated Signal Information

The instrument will provide digitized amplitude and position for the largest signal in each gate except for the front-face gate. The amplitude information will be in increments no larger than 1% of full screen (F.S.), accurate and repeatable to ± 2% F.S. (within the limits imposed by video signal variation).

The position information will be in units no larger than 0.1 microseconds. The zero position reference will be selectable between interface time and gate start time (for the front-face gate, selectable between initial pulse and gate start). The position will be accurate within 1% of the value or 0.1 microseconds, whichever is larger, and repeatable within the limits of video signal variation. The difference between position information for any two positions will be accurate within 1% of the actual difference between those positions.

The UT controller will select the gate(s) from which information is desired.

3.4.14.2 Alarm Information

The activation of any alarm will cause a signal capable of interrupting the UT controller. This signal will be repeated once during each repetition of the instrument cycle, until it has been acknowledged and the alarm has turned off. The instrument will inform the UT controller, upon request, as to which alarm(s) caused the interrupt.

3.4.15 Analog Output

Analog output for calibration and signal analysis will consist of a 50 ohm buffered RF signal (nominal 0.1 to 5.0 V peak-to-peak) and a selectable timing signal to enable gating of an external instrument on a given portion of the UT signal. The timing signal will be a TTL compatible pedestal coincident with a selected gate.

3.4.16 Digital Interfacing

Digital communication will follow the IEEE 488 spec, except that maximum total cable length will be as required for the UT system layout, and driver, receiver, and cable characteristics will be as required for that cable length.

Instrument-dependent communications will include all instrument control information and all gate information. Additionally, the signal digitizing instrumentation will be controlled by the IEEE 488 bus.

3.4.17 Signal Acquisition and Digitizing Instrumentation

The ultrasonic instrumentation will include a signal acquisition device capable of digitizing an ultrasonic waveform for use in digital signal processing for indication evaluation. The signal acquisition device may be an integral part of the UT instrument, or it may be a separate instrument. In either case, it will communicate via the IEEE 488 bus.

The instrument may be either a real-time or a sampling device. If it is a sampling device, then references to "time" in this section will be understood as "equivalent time," i.e., time as measured on an oscilloscope presentation of the repetitive signal.

The linearity, noise characteristics, and bandwidth of the acquisition instrument will at least meet the receiver specifications except that linear dynamic range is 20 dB. Input impedance will be 50 ohms. The minimum sampling time of the acquisition instrument will be 4 nanoseconds or less. It will be capable of acquiring and transmitting to the UT controller at least one data point during each repetition cycle of the UT instrument. It will acquire data during the time that the output rate from the UT instrument is high. It will be capable of acquiring at least 256 consecutive samples (in equivalent time, for a sampling instrument). The resolution will be at least eight bits, or 1 part in 256, with a sensitivity of at least 0.5 volts full scale, i.e., a resolution of approximately 2 millivolts at 0.5 volts full scale, 20 millivolts at 5.0 volts full scale, etc.

3.4.18 Transducers

Transducers will be high-damped, waterproof units, using UHF connectors, with O-ring seals.

The proper method of transducer characterization is a subject of much study and intense debate in the ultrasonic community. For a complex, sophisticated method, see, for example, Appendix II of Specification BNW 705-7. In the RFC system, transducer and system characteristics are comprehended within the signal analysis processing done on the digitized waveforms.

3.4.18.1 Damping

Damping will be adequate to permit required front-face resolution.

3.4.18.2 Frequency

Frequency will be measured by spectral analysis of the buffered rf output of the reflection from the front surface of the calibration fixturing. Peak frequency will be within 10% of manufacturer's specification.

3.4.18.3 Beam Pattern

The focal point will be the distance required to achieve maximum reflected amplitude (peak-to-peak rf) from the front surface of the calibration fixture. This value will be within 10% of that specified by the manufacturer. The beam symmetry will be measured at a distance of twice the focal distance. The half-amplitude contour will be mapped, using the digitized amplitude of the full-wave, wide-band reflection from the calibration fixture 1/8 in. (3.2 mm) sphere. This contour will not vary more than 20% from a circle centered at the point of maximum amplitude at that distance.

3.4.19 Acoustic Calibration Fixturing

The acoustic calibration fixturing will consist of a block or set of blocks, mounted in the inspection tank, containing a flat front surface, a 1/8 in. sphere, and internal reflectors. It will be constructed following the principles of ASTM E127-75.

3.4.19.1 Flat Front Surface

The fixture will contain an unobstructed front surface, at least 2 in. (51 mm) in diameter, with a specularly reflecting finish.

3.4.19.2 Sphere

The fixture will provide a 1/8 in. hemispherical surface, with a specularly reflecting finish, projecting at least 1/2 in. (12 mm) above the flat surface.

3.4.19.3 Internal Reflectors

The fixture will contain circular discontinuities of 0.015 in. (0.38 mm), 0.030 in. (0.76 mm), and 0.060 in. (1.5 mm) diameters, four of each, located 0.030 in. (0.76 mm), 0.060 in. (1.5 mm), 0.120 in. (3.1 mm), and 0.240 in. (6.1 mm) below the front surface. Flat-bottom drilled holes will be acceptable.

3.4.20 Enhancements

The following items are desirable, but have not been included as part of the basic specification because of higher risk in timely development of methods and equipment.

3.4.20.1 Satellite Pulser

The satellite pulser will be a miniature submersible unit for driving piezoelectric transducers with no cable intervening between the pulser and the transducer. The unit may include the transducer and/or a receiver. Each unit will operate in at least one of the frequencies and modes (transmit-receive or pulse-echo) specified in the description of the pulser, according to the specifications given there. The unit will generate a pulse in response to a timing signal from the pulser. The unit power supply voltage requirements will not exceed 24 volts rms (A.C. or D.C.). The units will be supplied in a sufficient variety of configurations (several interchangeable units) to permit operation in each of the frequencies and modes specified in the pulser description.

The purpose of this unit is to eliminate the impedance mismatches, and consequent energy losses and pulse distortions, incurred in cabling from the pulser to the transducer.

3.4.20.2 *Satellite Receivers (3 Required)*

The satellite receiver will be a miniature submersible device for amplifying signals from piezoelectric transducers with no cable intervening between the transducer and the receiver. The device may include the transducer and/or a pulser. Specifications for this device will be the same as for the receiver, except as follows: gain will be remotely selectable among 0 dB, 20 dB, and 40 dB; no frequency selection is required; output impedance will be 50 ohms; power supply voltage requirements will not exceed 24 volts rms (A.C. or D.C.).

The purpose of this device is to eliminate the impedance mismatches, and consequent energy losses and signal distortions, incurred in cabling from the transducer to the receiver.

3.4.20.3 *Backface Receiver and Gate*

The backface receiver will monitor for small percentage changes in the gated backface signal. It will be capable of discriminating changes as small as 0.1% of the signal amplitude, such as will be caused by a small flaw interrupting a wide sound beam.

The backface receiver will have digitizing and alarm capabilities. The digitized position will be specified for the other gates. The digitized amplitude will be in increments no larger than 0.1% of signal height. The current amplitude will be the moving average of the amplitudes from the most recent N instrument repetition cycles, where N may be chosen from one to ten. The alarm will trigger if the current amplitude falls below the previous amplitude by more than the threshold amount, where the previous amplitude is defined as the moving average of the amplitudes from N+1 to N+M repetition cycles prior to the beginning of the current cycle, where M may be chosen from one to ten. Relative amplitude will be accurate within ±5% of the measured change in amplitude, over a total amplitude range from 5% above to 10% below the reference amplitude.

3.4.20.4 *Phase-Insensitive Receiving Transducer*

The phase-insensitive receiving transducer will be used in conjunction with the backface receiver. The purpose of the phase-insensitive transducer will be to reduce the sensitivity of the backface monitor to slight variations in beam path due to mechanical motion and material inhomogeneities. It may be an array construction or other type (e.g., see Heyman, J., Acoust. Soc. Am., Vol. 64, No. 1, July 1978, pp. 243 ff).

3.4.20.5 *Three-Input Receiver*

To provide for a three-transducer angle beam inspection, as required for detection of a specular reflection from an axial-radial flaw, with backface monitoring, the receiver requires three-input capability.

One input will be used for the return echo to the transmitting transducer.

The other two inputs will be decoupled from the excitation pulse (at least 40 dB isolation). The inputs from the three transducers will be added and input to the common receiver circuitry. The summing circuits will be matched within 10% in gain and within 4.0 nanoseconds in time delay.

3.4.20.6 *Enhanced Position Resolution*

In order to perform dimensional inspection of parts, time resolution would require considerable enhancement. For measurements to the nearest 0.001 in. (0.025 mm) in titanium, with a published velocity of 6.1 mm/microsecond, a (round-trip) time resolution of 0.008 microseconds is required.

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX C
SPECIFICATION FOR RECOMMENDED MODIFICATIONS TO OVERHAUL FLUORESCENT PENETRANT INSPECTION

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APPENDIX C

SPECIFICATION FOR RECOMMENDED MODIFICATIONS TO OVERHAUL FLUORESCENT PENETRANT INSPECTION

1.0 SCOPE

This specification establishes general procedures for two modifications to conventional engine overhaul Fluorescent Penetrant Inspection (FPI) which may be implemented as part of the first generation Retirement for Cause (RFC) Inspection System. One of these modifications is a chemical milling pre-inspection surface preparation procedure. The specification will include details of a procedure which may be followed to assure proper selection and implementation of a chemical milling process for any critical engine component, but actual selection of chemical solutions and assessment of properties is beyond the scope of this current R&D program.

The second suggested modification to overhaul FPI is implementation of a hydrophilic penetrant system. Communications with personnel at Kelly AFB and Tinker AFB during recent months have indicated that hydrophilic systems will probably be implemented in the near term for general overhaul inspections. Therefore, the following recommendation will be complementary to existing ALC plans. Based upon experience gained during Air Force Contract "Methods Improvements of the Fluorescent Penetrant Inspection (FPI) Process" it is also recommended that a wet, water soluble Group VI developer be used with the hydrophilic system. Improved FPI capability to detect fatigue damage on properly prepared surfaces was shown using the wet developer vs. a dry powder developer.

Surface preparation procedures considered during assessment of suitable FPI method improvements included mechanical, chemical and combined procedures. The only surface preparation which promoted significant improvement of FPI over a conventional method described by Air Force T.O. was a chemical milling operation, as applied to nickel and titanium alloy specimens. Specimens had received simulated engine contamination before surface preparation.

FPI process modifications considered during assessment of suitable FPI method improvements included hydrophilic vs lipophilic systems, wet vs dry developers, penetrant and emulsifier dwell times, emulsifier concentrations, and stress enhancement. At this time stress-enhancement is not considered to be a suitable method improvement to suggest for general RFC application, although considerable improvement was noted when this form of enhancement was applied. This specification reflects the results of the studies performed on other process variables.

2.0 APPLICABLE DOCUMENTS

2.1 "Reliability of Nondestructive Inspection (NDI) of Aircraft Engine Components," Final Report On Phase I, Ward D. Rummel, Martin-Marietta, SAALC/MME MCR 79-678.

2.2 "Reliability of NDI On Aircraft Structures," Lockheed-Georgia/Air Force Program AFLC/SAALC/MME 76-6-38-1.

2.3 "Disk Residual Life Studies," Part II of AFWAL/P&WA Final Report AFML-TR-79-4173.

2.4 PWA Nondestructive Test Method Specification No. EIM 7

2.5 MIL-I-25135C

2.6 "Methods Improvement of the Fluorescent Penetrant Inspection (FPI) Process," Final Report, AFWAL-TR-80-4161, OCTOBER 1980.

2.7 "Improved Penetrant Process Evaluation Criteria," Final Report, August 1981, Air Force Contract F33615-80-C-5060.

3.0 SURFACE PREPARATION BY CHEMICAL MILLING

3.1 Materials and Equipment

3.1.1 Acid Cleaner

3.1.2 Alkali Cleaner

3.1.3 Chemical Milling Solution

3.1.4 Solution Tanks

3.1.5 Temperature Indicators

3.1.6 Timers (Mechanical or Electrical)

3.1.7 Solution Heaters

3.1.8 Fume Handlers, such as Exhaust Vents

3.1.9 Overflow Management Apparatus

3.1.10 Overhead Crane and Component Handling Equipment

3.1.11 Safety Equipment (such as gloves or automatic parts handling equipment)

3.1.12 Cold Water Pressure Spray

3.1.13 Clean Compressed Air Source

3.2 Controls

3.2.1 Operating Limits

3.2.1.1 Acid solutions to be maintained within a specified percent-by-volume range.

3.2.1.2 Aklali solutions to be maintained within a specified weight-per-volume range.

3.2.1.3 Chemical milling rate to be maintained within a specified range, as measured in inches per hour of material removal or other appropriate dimensions.

3.2.1.4 Some solutions will require strict control of temperature and continuous agitation.

3.2.1.5 Engine component surface finish must be substantially free of excessive roughness and undercutting.

3.2.2 Verification Frequency

Solutions must be checked often until experience allows verification at intervals of as many as forty to fifty component cycles. Required verification frequency will be strongly dependent upon sizes of engine components and solution bath.

3.2.3 Solution Verification

3.2.3.1 Acid Cleaner - pipette a small amount of solution into a flask, determine normality of acid, and calculate acidity percent by volume.

3.2.3.2 Alkali Cleaner - determine acid normality (N) using appropriate acid solutions, alkali cleaning factor (F), and alkali cleaner solution concentration. Alkali cleaner solution concentration may be calculated from the equation:

$$C = VNF$$

where: C = concentration of alkali cleaner
V = volume of acid used
N = normality of acid titrant
F = alkali cleaner factor

3.2.3.3 Chemcial Milling Solution - use a micrometer to measure thickness of a small test panel before and after a specified milling period. Surface finish will be checked by visual examination.

3.2.4 Solution Level Adjustment

3.2.4.1 Acid Cleaner - add acid or water to maintain percent-by-volume operation range.

3.2.4.2 Alkali Cleaner - calculate the amount of cleaner which must be added to maintain weight-per-volume operating range and add the specified amount of cleaner.

3.2.4.3 Chemical Milling Solution - milling rate and surface finish requirements will be maintained by addition of appropriate milling solution constituents.

3.2.5 Solution Replacement

3.2.5.1 Acid and alkali cleaners will be replaced when they fail to clean parts satisfactorily or contamination is suspected. An arbitrary time limit may also be established for solution replacement.

3.2.5.2 Chemical milling solution will be replaced when the milling rate and/or surface roughness cannot be controlled by the addition of appropriate solution constituents. The solution will also be replaced if contamination is suspected.

3.3 Requirements

3.3.1 Personnel performing surface preparation operations will be properly trained and certified by a qualified Level III Examiner.

3.3.2 Any variations from the established specifications or equipment malfunctions will be reported to the applicable NDE supervision.

3.3.3 The inspection area will be kept orderly at all times.

3.3.4 Applicable NDE supervision will assure that solutions are tested and maintained within assigned operating limits at proper intervals.

3.3.5 Timers and temperature indicators will be calibrated periodically, have calibration "due dates" posted on the instruments, and not be used if calibration is past due.

3.3.6 Solutions will be at proper indicated temperatures before components are processed.

3.3.7 All solutions requiring agitation will be constantly agitated while components are being processed and at least 15 min prior to processing.

3.3.8 Components which have been chemically milled will be suitably protected from contamination before FPI processing.

3.4 Design, Construction and Implementation

3.4.1 Chemical milling solutions will be chosen according to simplicity of constituents, environmental impact, controllability of nonselective milling, cost of operation, operator safety and effect on component mechanical properties.

3.4.2 Mechanical properties which must be assessed for etch degradation may include fatigue and high temperature creep.

3.4.3 All mechanical properties assessment will be conducted on specimens or components whose surfaces have received appropriate production finish (such as shot peen or vibratory barrel).

3.4.4 A sensitivity study will be conducted to determine critical process variables and to establish appropriate boundaries on those variables.

3.4.5 Alkali cleaning solutions will be chosen according to simplicity of constituents, environmental impact, cleaning effectiveness for removing residual smut, solution controllability, cost of operation, operator safety, and effect on component mechanical properties.

3.4.6 Alkali cleaner solutions will be subjected to rigorous assessment of effects on component mechanical properties and sensitivity studies of critical process variables as outlined above for chemical milling solutions.

3.4.7 Acid cleaner solutions will be chosen according to simplicity of constituents, environmental impact, effectiveness for neutralization of alkali cleaner, solution controllability, cost of operation, operator safety and effect on component mechanical properties.

3.4.8 Acid cleaner solutions will be subjected to rigorous assessments of effects on component mechanical properties and sensitivity studies of critical process variables as outlined above for chemical milling solutions.

3.4.9 Potential causes of smeared material on RFC components will be determined and extent of smear quantified. Potential sources of smear metal include mechanical surface preparation and galling.

3.4.10. Results of smear metal study will be used to determine proper chemical milling cycles.

3.4.11 Results of solution sensitivity studies will be used to calibrate system Operating Limits.

3.4.12 At least four solution tanks will be required to hold Chemical Milling Solution, Alkali Cleaner, Acid Cleaner and cold water. Tanks will be designed to resist attack and to be of large enough volume to allow reasonable adjustment periods for solution constituents.

3.4.13 Temperature indicators and timers shall be chosen according to accuracy, ease of calibration, readability, reliability and resistance to production environment.

3.4.14 Solution heaters must resist attack of the corrosive environment. Heaters will be sized to allow easy control of solution temperatures in a reasonable amount of time. Expense and power consumption must also be addressed. Steam and/or resistance heaters are commonly used for this type of application.

3.4.15 Fume handlers must resist corrosive attack, meet environmental and safety standards and be capable of fume removal in heaviest use of milling and cleaning stations.

3.4.16 Overflow management apparatus must resist corrosive attack, be capable of handling a major spill and meet environmental and safety standards.

3.4.17 Cold water pressure spray and the pure compressed air source will be free of contaminants such as oil.

3.4.18 Overhead crane and component handling equipment will be designed with consideration of such factors as size of engine components, resistivity to corrosive attack, safety considerations, reliability, maintainability, cost and ease of operation.

3.4.19 A reliability assessment of the overall FPI facility will be made and action taken to assure at least 50% operational capability of the facility in the event of a major system failure.

3.4.20 Safety equipment will meet all applicable standards and specifications.

3.5 Chemical Milling Procedure

3.5.1 The following procedure contains steps which are similar to those used by P&WA in production operations. Depending upon individual components and selection of milling solutions, etc., the procedure may not be entirely applicable.

3.5.2 Component may receive initial chemical cleaning to remove loose foreign materials.

3.5.3 Component may receive mechanical surface preparation, such as vapor blast, to remove scale and baked-on contamination.

3.5.4 Assure that component is free of dirt, oil and other foreign material before chemical milling operation. If part is contaminated, the chem mill operation may selectively attack surfaces.

3.5.5 Prepare component by immersion in temperature-controlled alkali cleaner for a specified time period.

3.5.6 Rinse in cold running water. If water breaks appear, repeat alkali cleaner step and rinse.

3.5.7 Immerse part in temperature-controlled agitated chemical milling solution for a time sufficient to remove the specified amount of material.

3.5.8 Immediately rinse in cold water.

3.5.9 Immerse part in temperature-controlled alkali cleaner for a specified time period.

3.5.10 Rinse in cold running water.

3.5.11 Cold water pressure spray to remove loose smut and reimmerse in cold running water.

3.5.12 Immerse in agitated Acid Cleaner Solution for a specified time period.

3.5.13 Rinse in cold running water.

4.0 HYDROPHILIC PENETRANT SYSTEM WITH WET, WATER SOLUBLE DEVELOPER

4.1 Materials and Equipment

4.1.1 Materials and equipment which are considered by this section are only those which will be required in addition to, or in place of, components of a conventional lipophilic system.

4.1.2 Group VI (MIL-I-25135C) Hydrophilic Emulsifier, such as Magnaflux ZR-10A.

4.1.3 Prerinse station between penetrant and emulsifier station.

4.1.4 Group VI (MIL-I-25135C) Wet, Water Soluble Developer, such as Manaflux ZP-13A.

4.1.5 Air agitator (or stir mechanism) and skimming weir for emulsifier dip tank, if dip mode is selected; or spray and recovery system may be installed for hydrophilic emulsifier application.

4.1.6 Dip tank with mild agitation for developer application.

4.2 Controls

4.2.1 Controls which are considered by this section are only those which will be required in addition to, or in place of, controls required of a conventional lipophilic system.

4.2.2 Hydrophilic emulsifier must be maintained within a specified concentration range and contain so little penetrant material that there is no appreciable background fluorescence after part emulsification over a reasonable period of time.

4.2.3 Wet, water soluble developer must be maintained within a specified concentration range and be thoroughly mixed to provide an even coating on FPI-processed components.

4.3 Solution Verification

4.3.1 Hydrophilic emulsifier may be checked on a continuous basis (concentration will be checked at least once every week). Emulsifier has a limited penetrant tolerance, so time required for acceptable removal of excess penetrant will increase as the bath is used.

4.3.2 Wet, water soluble developer will be examined periodically for contamination.

4.4 Solution Replacement

4.4.1 Hydrophilic emulsifier will be replaced when emulsification time required to eliminate background fluoresence becomes excessive (approximately six months to one year intervals). Addition of emulsifier instead of solution replacement is not recommended. An effective weir or penetrant skimming system at this station will prolong life of the emulsifier.

4.4.2 Wet, water soluble developer will be replaced if contamination is suspected.

4.5 Requirements

4.5.1 Requirements which are considered by this section are only those which must be considered in addition to, or in place of, requirements of a conventional lipophilic system.

4.5.2 Applicable NDE supervision will assure that solutions are checked and maintained within assigned operating limits.

4.5.3 Solution requiring agitation will be constantly agitated while components are being processed and at least 15 minutes prior to processing.

4.5.4 The hydrophilic system will have a prerinse station before emulsification to promote optimum useful life of the emulsifier solution.

4.5.5 The conventional dry developer station would be replaced by a station to apply wet, water soluble developer, and component drying would then be conducted after application of developer.

4.5.6 Timing of the emulsification step is more critical when using a hydrophilic system than when a lipophilic system is employed.

4.5.7 Some hydrophilic emulsifiers are biodegradable and have a finite pot life.

4.6 Design, Construction and Implementation

4.6.1 Items considered in this section are only those which must be considered in addition to, or in place of, a conventional lipophilic system.

4.6.2 An existing lipophilic emulsifier tank may be converted to a hydrophilic station by cleaning and rustproofing interior surfaces.

4.6.3 If dip mode is selected for the hydrophilic emulsifier station, agitation must be vigorous enough to apply a scrubbing action to engine components.

4.6.4 If spray mode is selected for the hydrophilic emulsifier station, solution spray must be of sufficient pressure to apply a scrubbing action to engine component surfaces.

4.6.5 If dip mode is selected for the hydrophilic emulsifier station, a skimming weir may be employed to prolong useful life of the emulsifier solution.

4.6.6 If spray mode is selected for the hydrophilic emulsifier station, a recovery system with suitable tank, filter and skimming apparatus may be employed to reuse the emulsifier.

4.6.7 The prerinse station will be located between penetrant and emulsifier stations. A water spray prerinse at 15 to 30 psi will be adequate. To meet environmental codes, a holding tank and oil separator may be required at this station.

4.6.8 To apply wet, water soluble developer, a dip tank with mild agitation will be installed before the drying station. It will not be necessary to dry engine components before developer application.

4.7 Fluorescent Penetrant Inspection Procedure

4.7.1 The following procedure contains steps which, (1) are recommended by vendors of inspection apparatus, (2) are similar to steps performed by P&WA in production and overhaul inspection, and (3) have been determined to produce optimum inspection for fatigue damage during United States Air Force Research and Development (R&D) programs.

4.7.2 Perform surface preparation according to Section 3.5. Normal overhaul surface preparation often leaves residual baked-on contamination on engine components. It is therefore recommended that a chemical cleaning process, followed by a mechanical process (e.g., vapor blast.) followed by chemical milling be employed to promote optimum FPI.

4.7.3 Parts will be clean and thoroughly dry before application of penetrant.

4.7.4 Post-emulsifiable Group VI (MIL-I-25135C) penetrant may be dipped, sprayed or brushed onto inspection surfaces. Magnaflux ZL-30 was used during Air Force R&D programs. Penetrant dwell time of 30 minutes provided optimum sensitivity.

4.7.5 Spray prerinsing is used to remove approximately 98% of the surface penetrant. A simple holding tank and separator may be employed to recycle penetrant and water.

4.7.6 Removal of remaining excess penetrant oil is performed at the emulsifier station. Hydrophilic emulsifier was applied at a concentration of 33% (dip mode) to achieve optimum FPI during several P&WA demonstrations. However, a spray application may be used and emulsifier concentration may be varied according to length of time desired for the emulsification step. Emulsification time of two minutes was shown to be optimum for detection of fatigue damage on properly prepared nickel and titanium alloy surfaces. The emulsification timing is more critical for a hydrophilic system than for a lipophilic system, since emulsification stops when parts are removed from the dip tank and dragout is minimal. Magnaflux ZR-10 emulsifier was used during two recent Air Force R&D programs.

4.7.7 Actual emulsifier solution contact time, dip or spray, must be determined experimentally and depends upon such factors as type of penetrant employed, remover, concentration, part size, geometry, surface finish, and age of emulsifier solution.

4.7.8 Final rinse may be conducted by dip or spray. A superior rinse is achieved by using a combination immersion rinse tank and touchup manual water spray rinse, and is especially effective on parts with restrictions such as tight radii and blind holes.

4.7.9 Wet, water soluble developer may be applied immediately after final rinse without drying engine parts. Magnaflux ZP-13A (dip mode) was used during United States Air Force R&D programs.

4.7.10 Hot air drying for a short period of time is used to produce optimum FPI indications.

4.7.11 Black light evaluation of indications.

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX D
SPECIFICATION FOR IEEE STANDARD 488-1978
DIGITAL INTERFACE FOR PROGRAMMABLE INSTRUMENTATION

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June 1981

DRAFT

CODE AND FORMAT CONVENTIONS

FOR USE WITH

IEEE STANDARD 488 - 1978

DIGITAL INTERFACE FOR PROGRAMMABLE

INSTRUMENTATION

[This draft incorporates those editorial and minor technical changes +
agreed upon by the IEEE SubCommittee on Instrument/Computer +
Interfaces as a result of the letter ballot on P728/D9, May 1981. +
Changes of a substantive nature made to D9 are marked with a |+| +
symbol in the margin.] +

FOREWORD

IEEE RECOMMENDED PRACTICE

This Recommended Practice is written as a companion for and extension to IEEE Standard 488-1978. The reader should be thoroughly familiar with IEEE Standard 488 to best understand and utilize the content of this document. Though written from the perspective of the device designer, users who design, assemble, or program systems will find this document helpful.

Since this document elaborates several different alternatives to accomplish equivalent or similar message transfers it is identified as a Recommended Practice (guidelines) rather than a Standard (in absolute terms). Information interchange applicable to IEEE Standard 488 has not yet matured to the point where a meaningful standard on codes and formats can be written. This Recommended Practice defines what is considered to be a useful set of code and format conventions. Users may inform the IEEE Standards office of any significant problems encountered in the use of this Recommended Practice by completing the form attached to this document.

NOTE
RELATION TO IEC PUBLICATION 625-2

This IEEE Recommended Practice deals, in part, with the same subject matter as IEC Publication 625-2, however the content of these documents is not identical. While the technical content of both documents are in general agreement where the subject matter is similar, the use of syntax diagrams and definitions contained in this document is thought to add significant clarity. In addition, this document contains recommendations for the format of character, string and block data not now contained in IEC 625-2. Users interested in interconnecting products designed to these two documents are cautioned to examine both the documents and related products in detail.

CODE AND FORMAT CONVENTIONS

CONTENTS

PREFACE

IEEE Standard 488-1978, "Digital Interface for Programmable Instrumentation" sets forth the device-independent mechanical, electrical and functional specifications necessary to support the configuration of programmable instruments using a byte-serial bit-parallel means to transfer digital data among interconnected instruments and apparatus. A fourth category of specifications dealing with the more operational aspects of an interface system is necessary to enable the configuration of an operational system. Operational specifications for systems and devices tend to be more device and system dependent. Program and measurement message formats, application software, and diagnostic routines, are examples of operational related capabilities. This Recommended Practice addresses the structure and format of several message types needed to support the more operational aspects of systems. No single code set and message format appears to be feasible, for use with IEEE Standard 488, and still support the overall objective of permitting a wide range of products and product capabilities to be interfaced. It is feasible, however, to define a limited set of guidelines and alternatives setting forth a number of different codes and formats generally applicable to products implemented with IEEE Standard 488 capability. The "Code and Format Conventions" of this Recommended Practice reflect the general customs and practice found useful for the exchange of device-dependent messages.

The word "code" as used herein refers to the pattern of bits in a device-dependent data byte (DAB message). Unless otherwise stated, the 7-bit coded character set used in this Recommended Practice is the ASCII 7-bit code*. The ASCII 7-bit code and its relation to the DIO lines of IEEE Standard 488 is defined in Sections 10 and 11.

The word "format" as used herein refers to the organization of data bytes within commonly used device-dependent messages.

This Recommended Practice uses the same letter mnemonics (e.g., END, SPAS, DAB) to refer to remote messages and interface states as used throughout IEEE Standard 488. Additionally, this Recommended Practice refers to several non-printing ASCII characters that are represented in text form by 2 or 3 characters although the message itself is both represented and sent by a single multiline coded character (e.g., new line represented by NL). These coded characters are identified throughout this Recommended Practice by underlined text (e.g., <u>CR</u>, <u>LF</u>, <u>NL</u>, <u>ETX</u>).

*ANSI X3.4-1977,"American National Standard Code for Information Interchange". The ISO 7-bit code is the equivalent international reference version.

1. SCOPE

This Recommended Practice elaborates a family of codes and formats to be generated, processed, and interpreted by the device functions of apparatus operating in concert with interface functions.

This Recommended Practice is intended to apply to both those devices with limited ability to generate, process, or interpret a variety of codes and formats as well as those devices that have extensive ability to generate, process, and interpret unique and very specialized codes and formats.

This Recommended Practice applies to the organization and content of messages at the machine-to-machine information interchange level, however, the guidelines set forth herein may have critical impact on both the related person-to-machine and machine-to-person information interchange.

This Recommended Practice applies to several device-dependent message types. Figure 1 shows the major relationships between this Recommended Practice and the related parts of IEEE Standard 488.

This Recommended Practice is intended to apply directly to instrumentation systems and may also apply to certain devices outside the scope of the instrument system environment.

2. OBJECT

The objectives of this Recommended Practice are:

1) To promote compatibility among different manufacturers' products,
2) To enable the interconnection of instrumentation and related devices with both limited and extensive capability to generate, process, and interpret a variety of different message types,
3) To define codes and formats that will minimize the generation of application software and system configuration costs,
4) To define a limited family of preferred message codes and formats in a relatively device-independent manner,
5) To permit direct communication among instrument system devices without extraordinary translation and conversion of special codes and formats.

3. SYSTEM CONSIDERATIONS

The purpose of an interface system is to carry device-dependent messages between devices, via interface functions, to and from device functions as shown in Figure 1. Device functions may differ from one another in several respects, and thus affect the

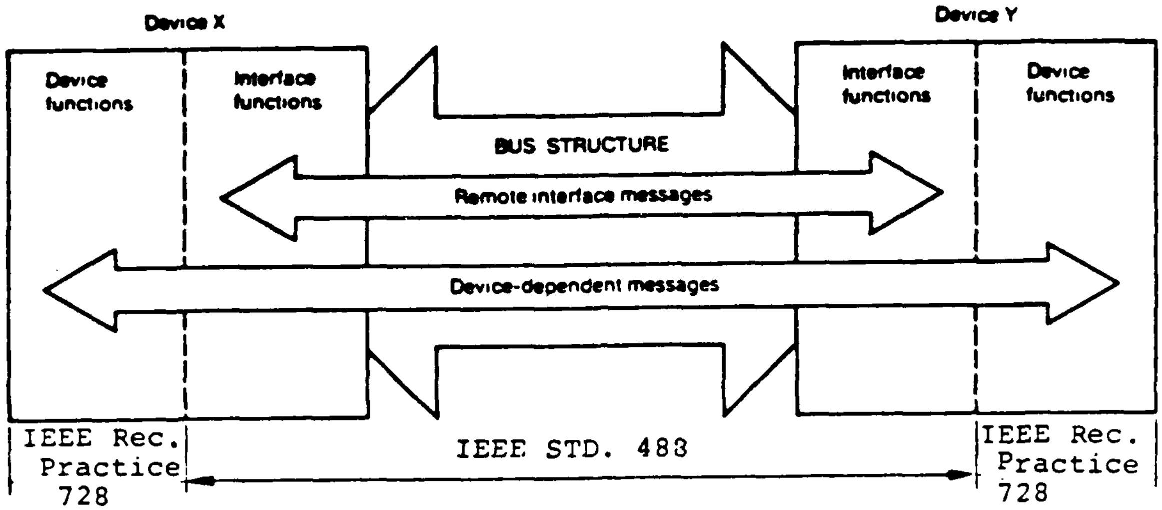


Fig. 1: Functions and Messages of the Interface System

nature of device-dependent messages that may be interchanged. The type and complexity of messages interchanged is, in part, determined by these factors:

1) ability of devices to generate, process, or interpret only a limited or single set of codes and formats versus an extensive or complex set of data codes and formats,

2) data transfered at machine level versus data initiated or consumed via human contact.

The type of system or systems a given product is to be placed in (i.e., other products it must communicate with and under what circumstances) has a significant impact on the nature of device-dependent messages that the product may be capable of generating, processing, or interpreting. The codes and formats used by a given product will determine, to a large extent, the range of configurations over which that product can be easily integrated. Therefore, careful consideration should be given to a device's code and format capability to ensure satisfactory system performance.

A designer should consider the range of products a given device is expected to communicate with and view potential applications from a broad perspective. Accommodation of more than one code or format may be necessary. Compatibility with a variety of products may be increased if messages are received "forgivingly" or interpreted without strict compliance to a specific format (e.g., accept variable data field lengths, ignore leading spaces). See Appendix D.

4. MESSAGE CONCEPTS

Most of the device-dependent messages described by this Recommended Practice are composed of a sequence of data bytes (DAB). A common structure and organization of the data byte sequence promotes compatibility among different products. This Recommended Practice sets forth the general organization and format for device-dependent messages and leaves the specific content of such messages to the designer.

4.1 Message Types and Definitions

Devices typically send and receive several different types of device-dependent messages. This section defines a set of message types considered to be useful for a variety of instrumentation system needs. It also defines the terms used to structure the description of these messages.

4.1.1 MESSAGE: A message, as used throughout this Recommended Practice, refers to one of four basic types: measurement, program, status, and display. The messages described herein are additional to and in concert with the terms "interface message", "remote message", "local message", and "device-dependent message" as used throughout IEEE Std. 488.

4.1.1.1 MEASUREMENT MESSAGE: A measurement message is a sequence of one or more measurement results separated by message unit separators, See Section 5.

4.1.1.2 PROGRAM MESSAGE: A program message is a sequence of one or more program instructions and optional message unit separators, See Section 6.

4.1.1.3 STATUS BYTE MESSAGE: A status byte message carries information about the internal condition(s) of an instrument's device functions. Devices send a status byte (STB message) in response to a serial poll to indicate one or more device function conditions (e.g., measurement complete, out of calibration, current limited). A status byte message is sent with a single status byte. See Section 7.

4.1.1.4 DISPLAY MESSAGE: A display message contains information displayed for operator convenience. Display data may contain a series of accumulated measurement results or a series of program instructions used to set-up a device. In either case, human interpretation is is important. See Sections 5, 6, and 8.

4.1.2 MESSAGE UNIT: A message unit is a single measurement result or a single program instruction.

4.1.2.1 MEASUREMENT RESULT: A measurement result is the output of an instrument's measurement process. Instrumentation devices typically output measurement information (e.g., frequency, voltage, current) as a result of performing a measurement. The general format of measurement results may contain both alpha information and a numeric value. A measurement result consists of a sequence of DABs that represent an optional header field and one mandatory data field. See Section 5.

4.1.2.2 PROGRAM INSTRUCTION: A program instruction is used to set-up and execute an instrument's measurement or stimulus function(s). Instrumentation devices typically receive program data (e.g., measurement range, operating mode, output mode) in preparation for performing a measurement function. A program instruction consists of a sequence of DABs that represents at least a mandatory header field and one or more optional data fields. See Section 6.

4.1.3 MESSAGE UNIT SEPARATOR: A message unit separator is always used to separate multiple measurement results from each other. It is optionally used to separate multiple program instructions from each other.

4.1.4 MESSAGE ELEMENT: Message elements are the basic "building blocks" of the syntactic constructs that define program and measurement messages. Major message elements consist of three types of headers, four data types, and three types of separators. Specific message elements are defined in Clause 4.3.

4.2 Message Overview

A device-dependent message of the type listed in Clause 4.1 represents an amount of information whose beginning and end can be defined or implied and whose contents are generated, carried, and interpreted together as a unit. These messages are considered to be further partitioned into specific fields to reflect identifiable portions of the message within a message unit.

In general, a device-dependent message is composed of several message elements or fields such as a header field (typically alpha), data field (typically numeric), and separator field (typically a symbolic character). Not all messages need to contain all possible message elements. Each of the message types identified in Clauses 4.1.2.1 and 4.1.2.2 may, for example contain a different set of message elements for diffferent applications to which the instrument or device is applied. Further, messages may be either isolated or grouped to form a continuous flow of messages as the specific application demands.

4.2.1 Simplified Message Structure

Figure 2 presents a very simplified structure for two common message types; measurement messages and program messages. The header field appears first in the sequence of DABs and is used to identify the nature of the value given in the data field of the message. The data field may contain numeric, string, character or block data types.

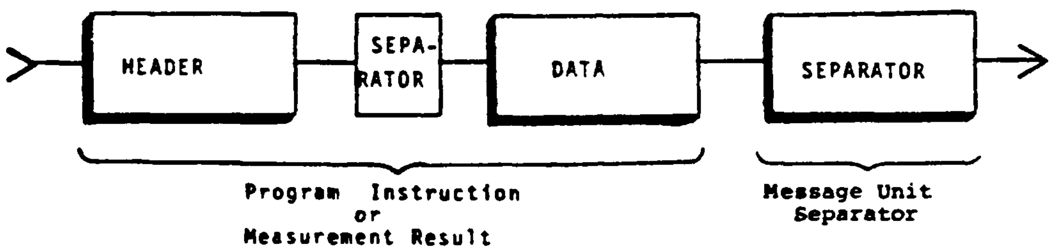


Fig. 2: Simplified Message Structure

The separator field is considered as a separate entity and is used by the receiving device to aid in the processing of the overall message. The separator is considered as optional and application dependent for certain message constructs as defined in Sections 5 and 6.

For convenience in further descriptions, each major message element is identifiable by letter designations; HeadeR Field (HR), Data Representation Field (DR) and Separator Field(SR). Subsequent Clause descriptions will further expand this notation for use in identifying the several format capabilities employed in various instruments. See Appendix B.

Status byte messages are sent within a single byte and hence do not utilize the same data fields. Instead subfields, all within the STB message specified by IEEE Standard 488, are defined throughout Section 7.

4.2.2 Syntax Diagram Notation

The generation and processing of measurement and program messages can be facilitated by defining the set of formats found most useful in instrumentation systems. Message format structure can be symbolized by syntactic diagrams that indicate allowable alternatives for the construction of specific messages from a sequence of data bytes. While the exact content of all data bytes is beyond the scope of this Recommended Practice, use of these general message formats should facilitate the interchange of information among devices.

The syntax diagram is a formal means to describe the preferred alternatives for constructing measurement or program messages. Each of the major message elements (HR, DR, SR) and their respective sets can be used to assemble messages for unambiguous processing and interpretation.

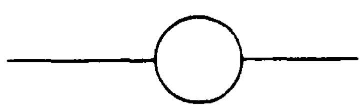
Devices, instruments in particular, are expected to send device-dependent data (in TACS) according to the message formats defined throughout this document. Both instruments and controllers can improve the level of information interchange by listening "forgivingly" when interpreting the message. See Appendix D for specific recommendations.

The syntax diagrams defined throughout Sections 4, 5, and 6 provide the basic definitions and message format structure for this Recommended Practice Further written description and examples serve to clarify and illustrate the use of these basic diagrams.

Syntax diagrams, comprised of six essential symbols, are used to define most of the message elements throughout this Recommended Practice:

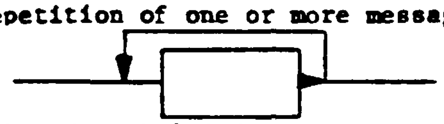
- rectangular shaped symbols indicate individual message elements that are explicitly defined elsewhere throughout this Section.

- circular shaped symbols indicate literal data (e.g., a specific ASCII character) the coding of which is defined in Section 10.



- arrows, left to right, indicate the assembly sequence of successive message elements and the by-pass paths around the indicated message element(s).

- reverse arrows, right to left, indicate feedback loops for the repetition of one or more message elements.



- rhomboid shaped symbol indicates concurrent transmission of the END message with a data byte (DAB).

- heavy lines indicate a preferred path within a syntax diagram, see relevant text for explanation of preference

In general, flow through a syntax diagram proceeds from left to right. Strategic location of arrowheads precludes disallowed paths through the diagram. Any circular or rectangular symbol without an exit path (line) implies the last byte of a message. The remaining clauses of Section 4 define the sets of major message elements available. Sections 5 and 6 utilize these building blocks to establish the preferred sets of measurement and program messages respectively.

4.3 Message Unit Elements

4.3.1 Header Field.

A header field may be used to describe the units (type, quantity) and/or quality of the data present in the data field it precedes. A header field may also be used to select a specific function.

In all cases, the initial character in an HR field is limited to an alpha character to facilitate parsing (partitioning) of messages by the receiving device. Three header fields are available as shown in Figure 3;

HR1 an alpha header,
HR2 a formatted header,
HR3 a character header.

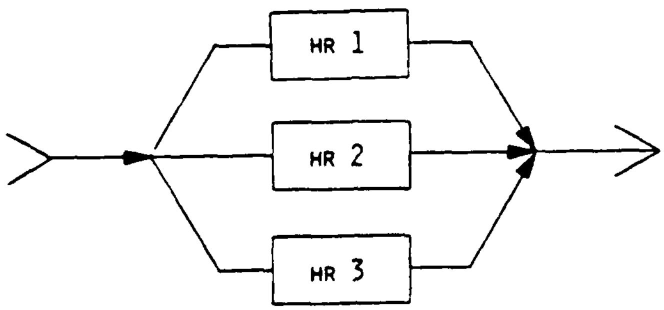


Fig. 3 HR Choices

4.3.1.1 Alpha Header (HR1)

A sequence of one or more alpha characters construced according to Figure 4. Alpha characters may be of either case, upper case preferred:

|A|B|C|D|E|F|G|H|I|J|K|L|M|N|O|P|Q|R|S|T|U|V|W|X|Y|Z|

|a|b|c|d|e|f|g|h|i|j|k|l|m|n|o|p|q|r|s|t|u|v|w|x|y|z|

Note: The symbol | | is used, here and throughout the document, to delineate the specified codes and, of itself, is not part of the code set.

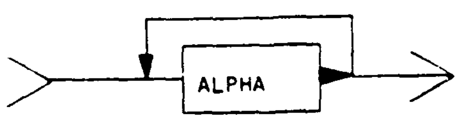


Fig. 4 HR Syntax Diagram

4.3.1.2 Formatted Header (HR2)

A sequence of one or more alpha character plus the possibility of embedded or trailing spaces constructed according to Figure 5. In some messages it is helpful to maintain the header at a fixed length for a given product employing a variety of type and quality indications. The use of embedded or trailing spaces is therefore useful.

Note: The symbol |SP| is used here, and throughout the document to indicate a "space" (ASCII code in column 2 row 0 of Table IV).

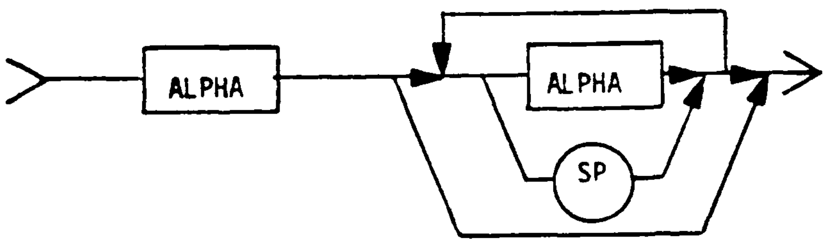


Fig. 5 HR2 Syntax Diagram

4.3.1.3 Character Header (HR3)

A sequence of one alpha character plus the possibility of additional characters following an initial alpha constructed according to Figure 6. In the additional character set these printable characters are allowed: +

Special characters:
|!|$|%|&|'|(|)|*|+|-|.|/|:|<|=|>|?|@|[|\|]|^|_|`|{|||}|~| +

Alpha characters:
[Upper and lower case as listed in Clause 4.3.1.1] +

Digits:
|0|1|2|3|4|5|6|8|9| +

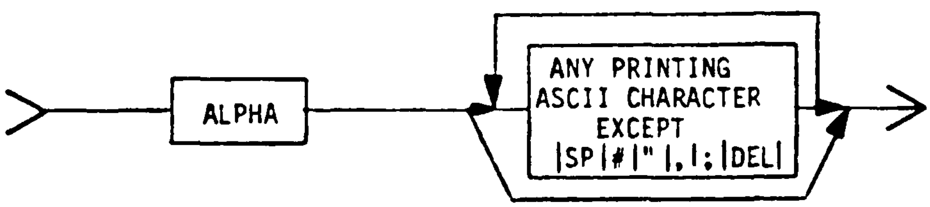


Fig. 6 HR3 Syntax Diagram

4.3.2 Data Fields

The central information contained within the body of each message unit may be represented by using one of four possible data types; numeric, string, block, or character. Some of these data types may be further sub-divided into more specific categories. This Clause sets forth the detailed syntactic description for each data field type. Subsequent Sections utilize these building blocks to construct measurement and program messages.

4.3.2.1 Numeric Data Type

The decimal positional representation of numeric values, commonly called numeric representation (NR) , may be implemented in any of three forms as shown in Figure 7; NR1, NR2, NR3. These representations are in general the ANSI X3.42-1975, "American National Standard for the Representation of Numeric Values in Character Strings for Information Interchange".

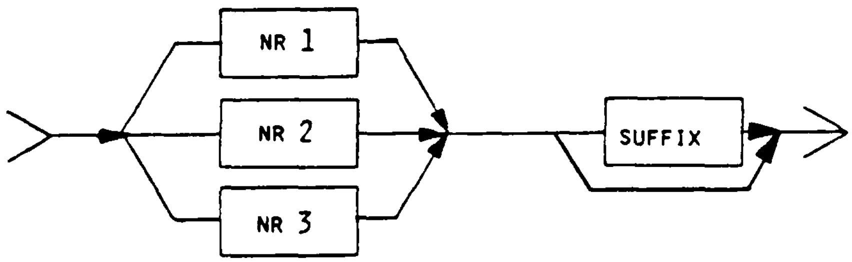


Fig.7 Numeric Representation Syntax Diagram

The NR1, NR2, NR3 representation applies only to the radix 10 with syntactic rules for the character set:

Numeric Digits = |0|1|2|3|4|5|6|7|8|9|

Special Symbolic Representations = |E|SP|+|-|.|

The number of digits contained in the NR1, NR2, or NR3 notation is unspecified. Within an NR field, the most significant digit (character) is sent first.

The NR syntax diagrams and associated examples use the + symbol to indicate the positive signed value of a number. Typical devices and common usage frequently delete the generation of and ignore use of the |+| sign. Unsigned numeric data is therefore allowed and interpreted to represent a value equal to or greater than zero.

4.3.2.1.1 Numeric Representation Set 1 (NR1).

NR1 consists of a set of implicit point representations of numeric values, i.e., a radix point is implicitly considered to be placed (fixed but not transmitted) at the end of the string of digits. Both the unsigned and the signed representation may contain leading spaces. There shall be at least one digit and no embedded or trailing spaces allowed. The signed representation of the numeric value ZERO is preferred to have either a plus sign |+| or |SP|. NR1 representation is useful for conveying numeric data of integer values. The syntax for NR1 is shown in Figure 8.

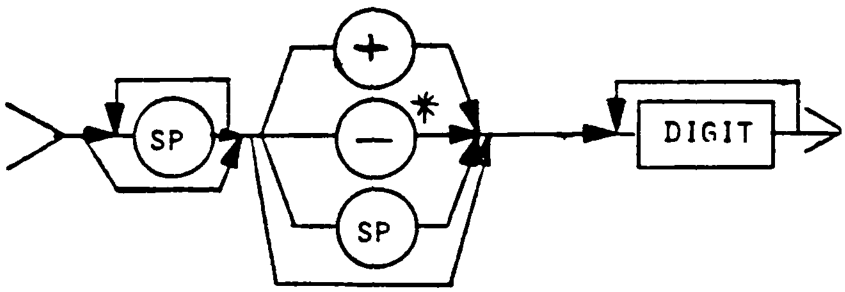


Fig. 8 NR1 Syntax Diagram

*Not preferred for ZERO valued numeric

4.3.2.1.2 Numeric Representation Set 2 (NR2).

NR2 consists of a set of explicit point representations of numeric values with the radix point indicated by a decimal point |.|. For clarity the radix point should be preceded by at least one digit, possibly 0. The signed representation of the numeric value ZERO is preferred to have a plus sign |+| or |SP|. No embedded or trailing spaces are allowed in NR2 representation. NR2 representation is useful for conveying numeric data that contains a fraction. The syntax for NR2 is shown in Figure 9.

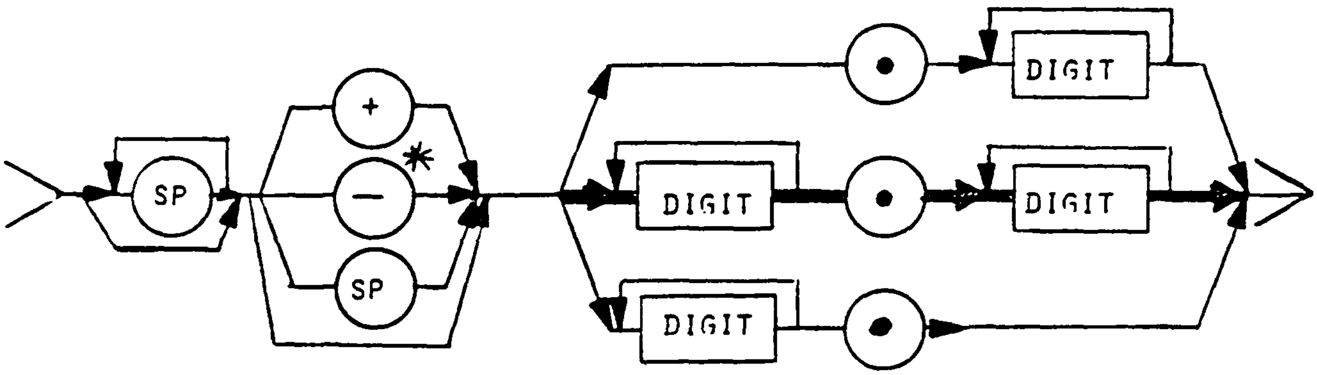


Fig. 9 NR2 Syntax Diagram

*Not preferred for ZERO valued numeric

4.3.2.1.3 Numeric Representation Set 3 (NR3).

NR3 consists of a set of scaled representations with either implicit or explicit radix point together with an exponent notation as shown in Figure 10. No embedded or trailing spaces are allowed in either the mantissa or exponent of NR3 representation. It is preferred that at least one digit, possibly ZERO, preceed the radix point |.|.

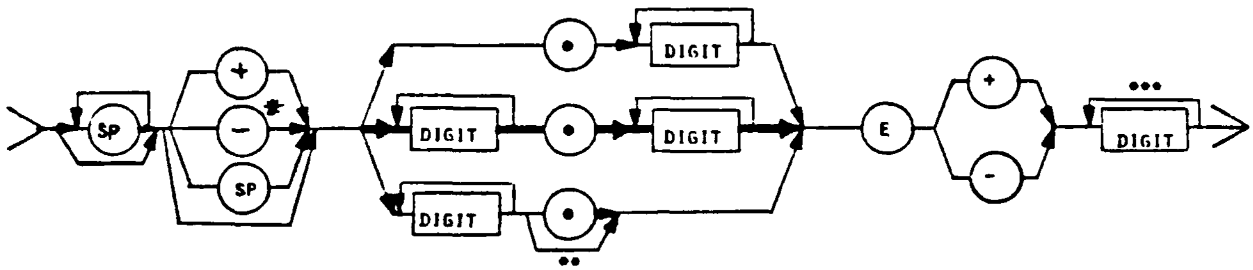


Fig. 10 NR3 Syntax Diagram

Notes:

(1) *Not preferred for ZERO valued numeric

(2) **ANSI X3.42-1975 NR notation allows for explicit-point-scaled representation only. Use of implicit point is allowed, not recommended for use with T or TE functions. All L, LE functions shall be able to handle both implicit and explicit forms. The implicit decimal point of the mantissa is assumed to be right-justified. L and LE functions shall accept unsigned NR3's as representing values equal to or greater than zero.

(3) *** Two digits preferred, expressed in multiples of three (e.g...06, 03, 00, -03..) for reasons of human interpretation and relationships to common physical units.

(4) NR3 representations that have an exponent with no sign should + be accepted.

(5) It is permissible to send a zero value mantissa with a non-zero exponent (e.g., 00000E+06). This representation is not preferred.

Common Notation	0	.00015	-10	-14.203	1234.5	5600
Signed NR1	+0	No Rep	-10	No Rep	No Rep	+5600
Unsigned NR1	0	No Rep	No Rep	No Rep	No Rep	5600
Signed NR2	+0	+.00015	-10.	-14.203	+1234.5	+5600.
Unsigned NR2	0.	.00015	No Rep	No Rep	1234.5	5600.
Preferred NR2	0.0	0.00015	-10.0	-14.203	1234.5	5600.0
Signed NR3	+0E+0	+1.5E-4	-1E+1	-1.4203E+1	+1.2345E+3	+5.6E+3
Unsigned NR3	0E+0	1.5E-4	No Rep	No Rep	1.2345E+3	5.6E+3
Preferred NR3	0.0E+00	150.0E-06	-10.0E+00	-14.203E+00	1234.5E+0	5.6E+03
With Suffix	0V	0.00015A	-10V	-14.203V	1.2345KHZ	5.6KHZ+

NOTES:

1) Although not used in the above examples, leading spaces and/or zeros are allowed.
2) The number of digits in these examples does not imply a preferred quantity of digits to be transferred.
3) A ZERO value with a minus sign is not preferred.
4) "No Rep" means no representation possible.

TABLE I Numeric Representation Examples

4.3.2.1.4 Suffix

One special form of numeric representation (beyond the scope of ANSI X3.42-1975) useful in instrumentation systems permits use of a suffix following the numeric value whether the NR is represented in NR1, NR2, or NR3 form. The suffix is related closely to the NR in that it expresses the associated units; unscaled units preferred or with units multiplier if necessary. This suffix is expressed as a series of characters as shown in Figure 11. See Appendix C for typical suffix multipliers and units. See Appendix A for typical examples of the use of a suffix.

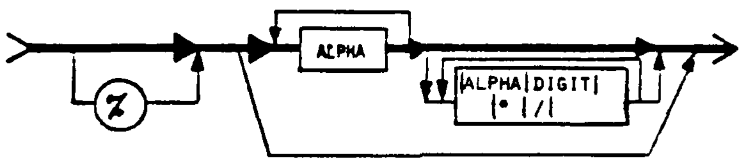


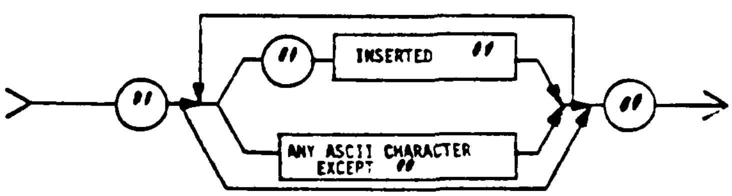
Fig. 11 Suffix Syntax Diagram

The non-preferred suffix path may be used to permit more human readable formating of data output to devices such as printers and CRTs (e.g., 12.5% or 12.5 meters/second).

4.3.2.2 String Data Field

The string data field allows ANY character in the ASCII 7-bit code (including non-printable characters) to be carried as a message. This data field is particularly useful where text is to be displayed (e.g. on a printer or CRT type device). Using the string data type permits the use of format effectors such as |CR|LF|SP| to correctly format text. Each string data field begins and ends with |"|. It is possible to include the quotation marks character |"| within the text by sending two sequential characters |""|. The string data syntax is given in Figure 12.

Fig. 12 String Syntax Diagram



4.3.2.3 Block Data Field

The block data field allows ANY 8-bit data type (including extended ASCII codes) to be carried as a message. It is particularly useful for sending large quantities of data. Since the focus of the block data field is to provide for long data streams, a means to increase data transfer reliability has been included via error detection.

A block data field is initiated by a UNIQUE CODE, the number |#| sign. THE |#| CODE IS NOT ALLOWED IN ANY OTHER IEEE 488 device-dependent message EXCEPT: (1) within the string data field and, (2) within the block data field itself.

The block data field is used within the context of both the measurement and program messages as defined in Sections 5 and 6. In addition, the block data structure can exist as a separate entity (e.g., it can stand alone for the transfer of files). It is also possible that an entire measurement or program message can be sent within the DABs of the block data field to take advantage of the error detection capabilities. The syntax for the block data field is given in Figure 13.

The data fields throughout this clause are intended to provide common syntax structures for a broad range of block data types and, as such, represent a set of recommended general purpose solutions. More specialized applications requiring greater data field efficiency, shorter lengths or greater integrity, for example, may demand alternate block structures beyond the scope of this Recommended Practice.

Within the data field the most significant DAB shall be sent first.

Designers should consider the implications of buffer size and availability, particularly in the intended receiving devices. It is not to be assumed that all devices will automatically be capable of accepting lengthy messages.

Rationale for the selection of the appropriate error detection means is given in Clause 4.3.2.3.3.

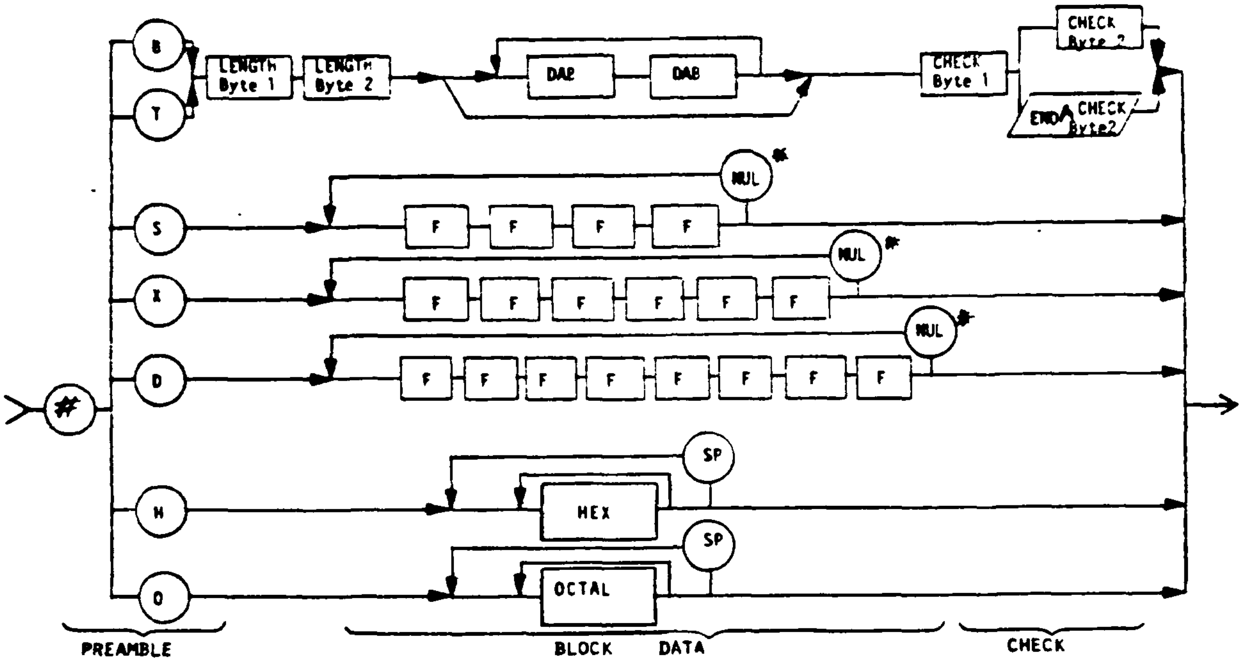
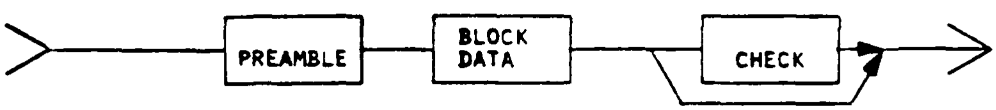


Fig. 13 Block Data Syntax Diagram

* NUL is not a unique code, therefore receivers may check every fifth, seventh, or ninth block data byte (for S,X,D representations respectively). If the byte is a "NUL" another floating point number will be sent/received. Some applications (e.g., DMA transfers) may prefer multiple floating point numbers to be sent without "NUL" to simplify direct block transfers.

Throughout the balance of this document the block syntax diagram will be represented in a simplified form as expressed below in Figure 14.



Simplified Block Data Syntax Diagram
(used in Figures 21 and 23)

4.3.2.3.1 Block Preamble

The preamble consists of two bytes the first of which is the |#| byte. A second byte designates which of seven possible data types are to be represented within the block by the data bytes.

Identifier	Data Type	Usage
|B|	Binary	Data byte sequence(format) and coding is device-dependent
|T|	Text	ASCII DAB sequence is device-dependent, bit 8 is a don't care bit, sent false if the application permits.
|S|	Single precision	DAB's represent numbers expressed in single precision floating notation, 4 bytes per number. (See Appendix E)
|X|	Extended Single Precision	DAB's represent numbers expressed in extended single precision floating point notation, 6 bytes per number. See Appendix E)
|D|	Double precision	DAB's represent numbers expressed in double precision floating point notation, 8 bytes per number. (See Appendix E)
|H|	Hexadecimal	A sequence of DAB's representing hexadecimal data
|O|	Octal	A sequence of DAB's representing octal data.

Note: No other identifier characters are allowed!

4.3.2.3.2 Block Length Bytes

The length bytes contain information about the number of bytes in the block, the condition that terminates the block, the the nature of the last byte, and the type of error detection used (if any). The length byte bit assignments for L12 through L0 represent an unsigned binary integer that indicates both the number of data bytes to follow and how the block will be terminated. Total data byte count is to be maintained at an EVEN number. The length byte bit assignments are given below.

	Length Byte 1								Length Byte 2							
DIO>	8	7	6	5	4	3	2	1	8	7	6	5	4	3	2	1
	F	C1	C0	L12	L11	L10	L9	L8	L7	L6	L5	L4	L3	L2	L1	L0

Where: F= Odd/Even flag bit for last data byte
C0= Checksum error detection usage
C1= CRC error detection usage
L0-L12= Length count

Bit Values	Meaning
F Code	
F = 0	Even data byte length: all data bytes used to carry information, no fill bytes used.
F = 1	Odd data byte length: last data byte is fill to maintain even byte count. The contents of the fill data byte are a "don't care".

See both UNSPECIFIED block lengths for exception +

C1 C0 Coding

C1 C0	Coding
0 0	No error detection used, check bits all=0
0 1	Checksum detection means is used: Check byte 2 contains modulo 256 check sum of the data bytes. Check byte 1 contains the 1's complement of check byte 2. [The length bytes are excluded from the checksum].
1 0	CRC16 Forward error detection is used: the CRC is performed on the data and check bytes. See Clause 4.3.2.3.2.3 for CRC polynomial specifications. [The length bytes are excluded from the the CRC].
1 1	Reserved (not to be used)

L0...L12 =

L0...L12 =	
2,4,6,....,4098	The integer decimal equivalent of these 13 bits specifies how many bytes are to follow. The count includes all data bytes and the two check bytes. (Maximum data bytes = 4096)
4099	The block contains an UNSPECIFIED even (See special note of exception below*) number of data bytes up to a maximum of of 4096 plus 2 check bytes. END shall be sent concurrent with last check byte.
8191	The block contains an UNSPECIFIED even (See special note of exception below*) number of data bytes plus 2 check bytes with no limit to the maximum number of bytes in the block. END shall be sent concurrent with last check byte.
All other values	Reserved (not to be used).

Note *: If an even number of data bytes can be assured, then F=0 shall be used. If EITHER an odd or even data byte length can result due to a data source of indeterminant length, then F=1 shall be used (only with length counts of 4099 and 8191) with the assumption that the number of data bytes can be odd or even.

4.3.2.3.3 Block Check Bytes

Two check bytes shall always be used. The check is performed on only the data bytes (DABS).

If no error detection means is used, then both bytes shall be sent NUL.

If a checksum error detection means is used, then check byte 2 contains the modulo 256 checksum and byte 1 contains the 1's complement of check byte 2.

If a CRC16 Forward error detection means is used, then the two byte count sent with the data bytes contains the remainder from division of the data byte stream by the CRC16 Forward polynomial (i.e., $x^{16} + x^{15} + x^2 + 1$). The receiving device remainder is then zero for an error-free message. The parallel data on DIO8 to DIO1 shall be serialized most significant bit (DIO8) first.

NOTE: The designer must ensure that the CRC circuitry can be enabled within 4 bytes times.

Rationale for the selection between the two detection means is as follows;

It is recommended that the CHECKSUM be used when short blocks of data are sent (e.g., 15 bytes/block is a typical number). A checksum is insensitive to multiple errors resulting in a "no-error" indication from the checksum calculation. If the probability of a double error in the block is small, the user may choose the checksum method for single error detection.

It is recommended that the CRC16 polynomial method be used when the system is less sensitive to multiple errors yielding a "no-error" condition. Due to the nature of CRC16 technology the resultant error check is dependent to a significant degree on longer historical data patterns. The probability of multiple errors causing a "no-error" output of the error detection circuitry is less than the checksum method. The CRC16 approach is recommended where longer data blocks are being transferred. It is also recommended where the failure of error detection is critical and not to be tolerated.

4.3.2.4 Character Data Field

The character data field is used where words and text more clearly describe the nature of a program instruction than does a numeric data field. Character data fields always begin with an alpha character. The use of alpha characters only is preferred. Digits and other special purpose characters should be used only where the human readability and interpretation of the header is thereby enhanced. The character data syntax is shown in Figure 15.

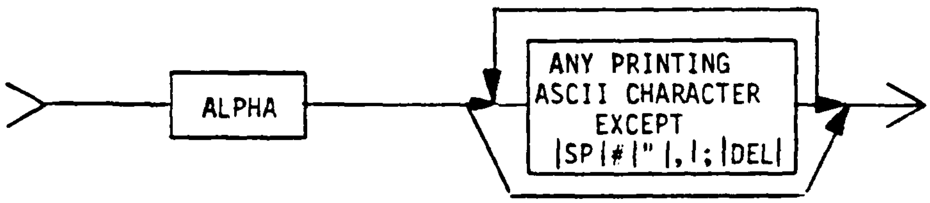


Fig. 15 Character Syntax Diagram

4.3.3 Message Separators

A means to distinguish between one message unit and the next message unit or between information fields within message units is useful and sometimes essential for unambiguous message processing. Such means are useful for conveying related sets of data that occur in pairs (e.g., amplitude and phase) or other data set multiples (e.g., time, channel, frequency) or long continuous message streams.

Message separators may be needed before a talker function exits the TACS state and at certain times throughout a TACS condition. The context in which the separators are described assumes normal message traffic without controller initiated interruption of a message sequence.

Separators fall into three broad categories based on a hierarchical relationship to one another. Although several categories contain multiple choices for separator usage, the relative hierarchial relationship is retained. Separators are not mandatory for all syntax structures (see Sections 5 and 6) as it is possible to construct message formats with implicit separation between message elements.

Provisions have been made for both simple and complex parsers in receiving devices. Some parsers may be able to make the information field separation implicitly, that is, separator characters are not required. For implicit separation the receiver knows what type of information is expected based on preceeding or following characters. Other parsers may require explicit use of any or all of the three categories (levels) of separators.

IEEE Std 488 identifies the existence of two separator types without defining explicit usage, relationships to message formats, or coding. The END message ranks at the top of the hierarchy whereas the EOS message is at a lower level. This document defines three basic levels of separators for use with measurement and program message structures. The separators listed in descending order of the hierarchy are; SR3, SR2, SR1.

Figure 16 illustrates a very general structure for separator usage.

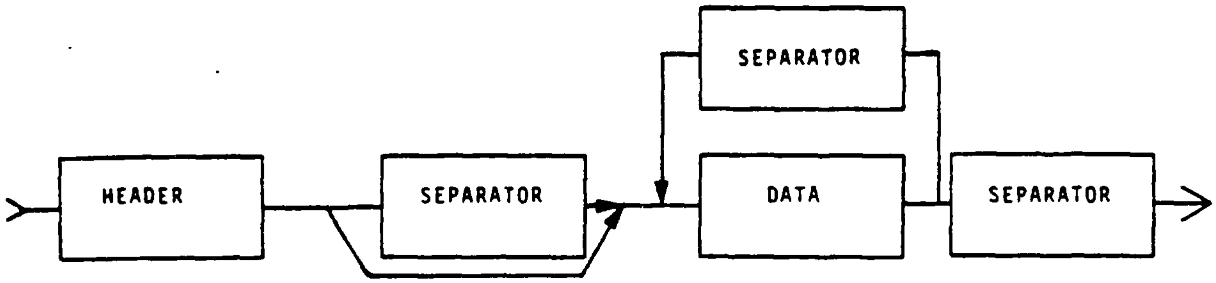


Fig. 16 Typical Separator Use

4.3.3.1 Separator Level 1 (SR1)

An SR1 separator is typically used to identify the end of the lowest level of message element or data field(s). Two separators exist at this level; the comma |,| and semicolon |;|. The lowest order separator of these two is the |,| and is, for most applications, the preferred separator. This is based on the fact that the comma |,| is of lower order than the |;| in the written word. The syntax for SR1 is given in Figure 17.

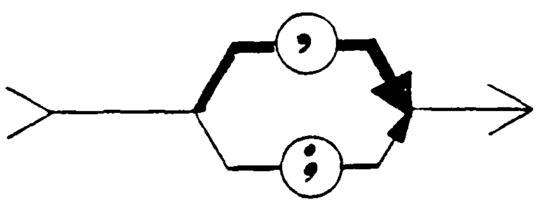


Fig. 17 SR1 Syntax Diagram

4.3.3.2 Separator Level 2 (SR2)

An SR2 separator is typically used to separate a sequence of message units at a distinctly higher level than that of the SR1 separator. There is only one level of separator at the SR2 level although there are several implementation choices. The syntax of SR2 is given in Figure 18.

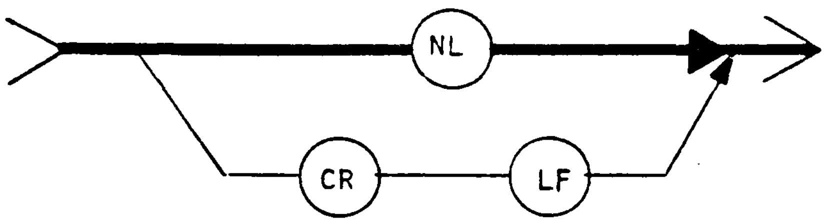


Fig. 18 SR2 Syntax Diagram

NOTES:
1. ASCII code for NL is identical to LF.
2. The ability to select between the SR2 separator paths within a device will provide more universal information interchange.
3. FUTURE: The long term intent is to use a SINGLE character for the SR2 separator. Use of the double CRLF character separator (alternate path) within a device may be needed for some time to facilitate compatibility with existing products.
4. PAST/PRESENT: For broad compatibility the syntax path for the T (TE) function has been/is CRLF whereas the preferred path for the L (LE) function is LF or NL. The L function should use LF as the separator and NOT the CR character. The CR character should be discarded unless the device (like a printer) is capable of executing the CR operation.

4.3.3.3 Separator Level 3 (SR3)

The SR3 separator is the highest order separator specified by this Recommended Practice. An SR3 separator is usually used when one or a series of measurement or program messages has been completed. As the highest order separator, the SR3 or END message has special significance. A talker, having sent END, shall not output further DAB's automatically. The "talker" must then receive a device-dependent message or a specific interface message (e.g. GET) prior to resuming output. Systems using the local ton (talk only) message may resume output via an external stimulus such as "manual trigger". The SR3 syntax is given in Figure 19.

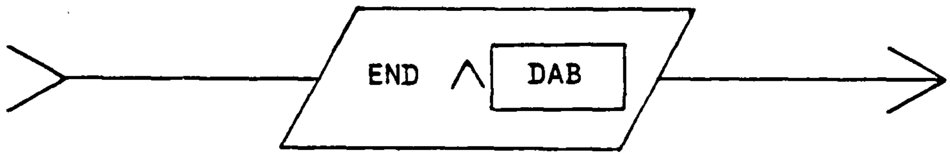


Fig. 19 SR3 Syntax Diagram

Notes: 1) The END message (sent on the EOI signal line) is sent concurrent with DAB and follows identical timing requirements (see Clause 2.3.3.4 of IEEE Std. 488-1978).

2) DAB is a device-dependent multiline message encoded on DIO1-DIO8. DAB may be a normal data byte or one of the other lower order separators as specified in subsequent diagrams.

4.3.3.4 Leaving and Entering TACS/LACS.

The use of SR1, SR2, and SR3 separators shall not imply that a given device will automatically exit the TACS or LACS states.

Any data transfer may be interrupted synchronously by the controller function to achieve other higher priority operational sequences. It is recommended that the interrupted device resume data byte transfer with the next byte following the byte transmitted prior to the point of interruption (data transfer resumes when the device re-enters TACS). It is recommended that asynchronous interruption of a message be avoided as it is difficult (if not impossible) to determine whether the byte being transferred at the time of interruption was received.

4.3.3.5 Separator Coding

The allowable codes for separators are given in Table II. This is a summary coding table representing a composite of the SR capabilities defined throughout Clause 4.3.4.

Separator	Code	Remarks
SR1 (Level 1)	|,|;|	See Note 1
SR2 (Level 2)	|NL|CRLF|	See Notes 2,3
SR3 (Level 3)	END	Sent on EOI, See Note 3

TABLE II SEPARATOR CODING SUMMARY

Notes:

(1) To facilitate explicit parsing between the header and data fields in some applications an exception to the above SR1 coding schema is required. For a restricted set of conditions one may use the |SP| header separator between header and data fields. See Figure 8B for details.

(2) The NL (new line) or LF (line feed) is preferred over the CRLF code pair as the SR2 separator. Use of multiple bytes to perform the separator function may lead to an ambiguous response in some devices. Therefore, use of the single byte NL (ASCII code column 0 row 10, same code as LF) is preferred to perform the SR2 separator function. All these codes are format effectors*.

(3) The ETB and ETX codes defined in the ASCII code may be found as record separator and terminator respectively in some international use of the related IEC Std. 625-2. The ETB and ETX codes are ASCII comunication control* characters and therefore should be used with caution. Neither code is recommended as a means to effect separator action.

* Refers to ANSI X3.4 terminology

5. MEASUREMENT MESSAGES

Instrumentation devices perform many measurement functions. Typical tasks like measuring frequency or voltage, digitizing a waveform, and performing network analysis result in the generation of measurement results. The specific content of the message is device-dependent, however the organization or general format of these application dependent messages can be structured in a way common to many devices. The purpose of this Section is to establish a set of recommended practices for the format of measurement messages such that information interchange among independently designed devices is achieved at the highest level possible.

5.1 Measurement Message Overview

The individual syntax diagrams defined throughout Section 4 may be used to construct and assemble specific measurement messages suited to unique applications. A generalized form of typical measurement messages is given in Figure 20 below to introduce the normal flow of data fields, the "format" of the message. The reader is cautioned not to design to this diagram: it serves only to introduce the general flow of information.

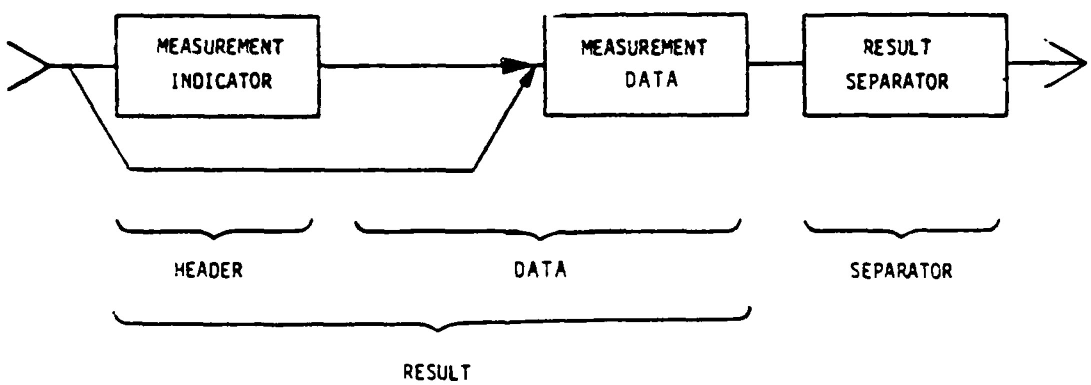


Fig. 20 GENERAL FORM: MEASUREMENT MESSAGE

The combination of a header and the measured data itself form what is termed the measurement result. This is equivalent to a single message unit. Some form of separator is then used to distinguish this result from the next one. The optional nature of the header is denoted by the bypass path around the header element. Note that for measurement messages the data and separator fields are mandatory!

5.2 MEASUREMENT MESSAGE FORMATS

This clause sets forth the explicit syntax for a common set of measurement messages in a way considered to be relatively device and application independent. The specific content of each message element, at the lowest level (e.g., semantic meaning of the letter P), is beyond the scope of this document. Figure 21A sets forth the preferred syntactic construction of the three different types of measurement results identified as numeric data, string data, and block data. Figure 21A is to be viewed as a SINGLE measurement message, one result. Many real applications, of course, require a series of results. Figure 21B will indicate the method(s) available to achieve a variety of more complex messages.

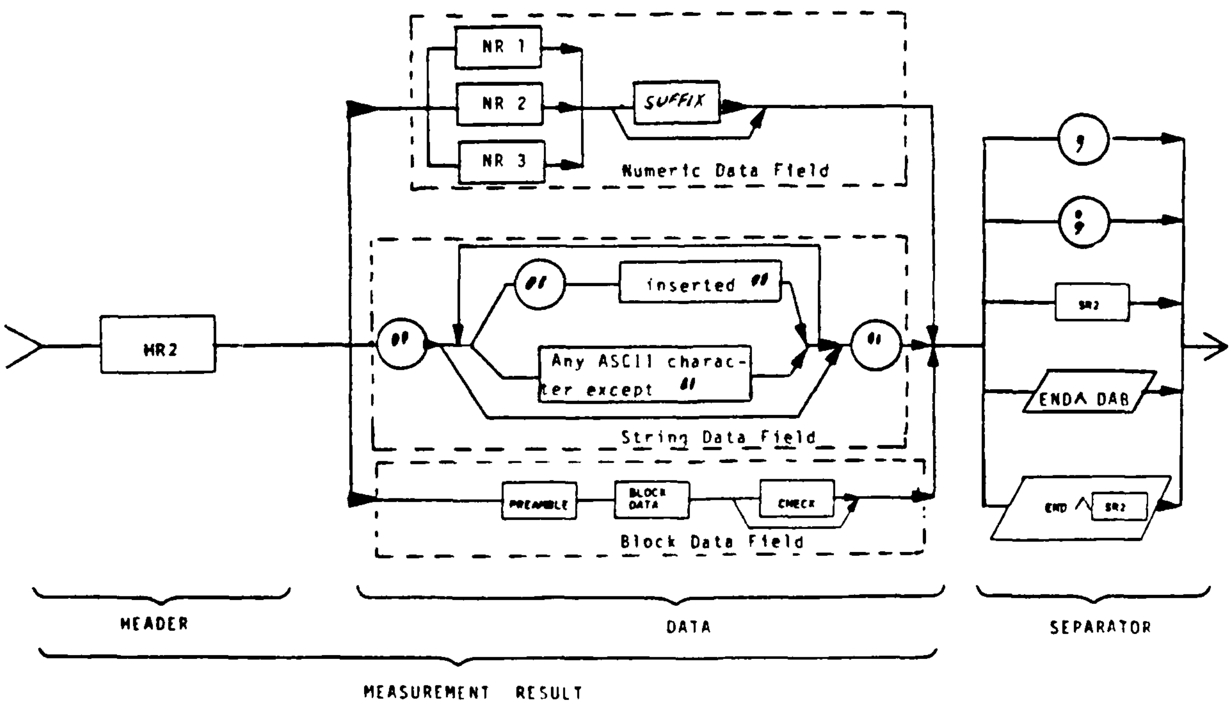


Figure 21A, Measurement Message Syntax Diagram

5.2.1 Measurement Message Construction

These guidelines and recommendations are provided to facilitate the construction of measurement messages intended for the highest level of interchange possible between independently designed devices.

5.2.1.1 General

- To accommodate a wide variety of measurement devices the measurement message may contain any number of DABs.

DABs are sent most significant DAB first for numeric data.

5.2.1.2 Header Field

5.2.1.2.1 The preferred HR field should contain only alpha characters. This facilitates reading of the NR field with free-field formats in common use. The HR field is particularly useful where human readibility is important.

5.2.1.2.2 The HR2 field is optional and, if used, should be as short as possible. For a known product, in a specific mode, a fixed length HR2 field greatly facilitates parsing of the data fields by the listener. All characters, including embedded spaces, make up the HR field. Spaces may be used to maintain a fixed length HR.

5.2.1.2.3 The HR2 field, when used to specify units associated with the NR data field, shall use unscaled units as the preferred set (e.g., volts, ohms, amperes). If scaled units are used then the preferred values should be in multiples of 10^{+3} or 10^{-3} (e.g., UF, MV, KA, MM). The NR suffix field may, in addition, be used to specify the units and multiplier relating to the numeric data field in which case unscaled units are preferred.

5.2.1.2.4 If the HR2 field refers to data quality, then device-dependent alpha characters may be used to indicate specific conditions. For example; calibration voltage may be represented by CV.

5.2.1.3 Data Field

It is MANDATORY that at least one of the data fields be used in a given measurement message.

5.2.1.3.1 Numeric Data

- The NR field shall contain either an NR1, NR2, or NR3 value, the choice is application dependent.
- NR1 implicit point representation is most useful for numeric data where either limited interpretation or generation of data is required (e.g., restricted or fixed-range) and also where large volumes of fixed format data or high speed data are transferred between devices. In these applications data rates are of primary significance.
- NR2 explicit-point unscaled representation is most useful for numeric data where either the range of data output is limited or data is intended to be used with devices where human interpretation is prevalent.
- NR3 exponential notation is preferred where measurement or controller devices must accommodate a wide range of values or where the specifc range of data to be output (or input) is unpredictable.
- A constant length NR field length for a specific operating mode may facilitate efficient data interpretation and storage. For a given operating mode the selected type of NR representation should remain the same, even through ZERO values.

5.2.1.3.2 String Data

- The string data type is intended where the message is to be displayed for human interpretation as on a printer, plotter, or display unit.

- The ability to carry any ASCII 7-bit character enables the message to contain non-printing characters and thus messages can be readily formatted for ease of human interpretation.

5.2.1.3.3 Block Data

- Block data is intended to be used where the message is of extended length.

- Block data supports relatively transparent data transmission and thus provides for the capability of sending binary data messages.

- To increase the data integrity for long message lengths, several alternate check means are provided. The rationale for the use of each check method is given in Clause 4.3.2.3.3.

- Each block data field requires mandatory preamble consisting of the |#| flag followed by an alpha flag. The block data set is limited to seven explicit choices;
  - |B|T| fields contain explicit length and check mechanisms
  - |S|D|X| fields support floating point numbers, have neither length nor check mechanisms and use the |NULL| code to separate multiple values
  - |H|O| fields are used to represent non-decimal data with a selected set of ASCII codes;

- Designers should consider the impact of buffer size and availability and not assume that recipients of long records will be capable of accepting such records automatically.

5.2.1.4 Separator Field

- Each result shall be terminated with one of the separators identified in Figure 21A.

- Guidelines for the selection of a specific separator are given in Figure 21B to accomodate the construction of more complex messages containing more than one result.

- Use of the END message indicates the device expects to be further instructed (i.e., receive a device-dependent message or an interface message such as GET) before another measurement data message is output. Systems using the local ton (talk only) message may resume output via an external stimulus such as "manual trigger".

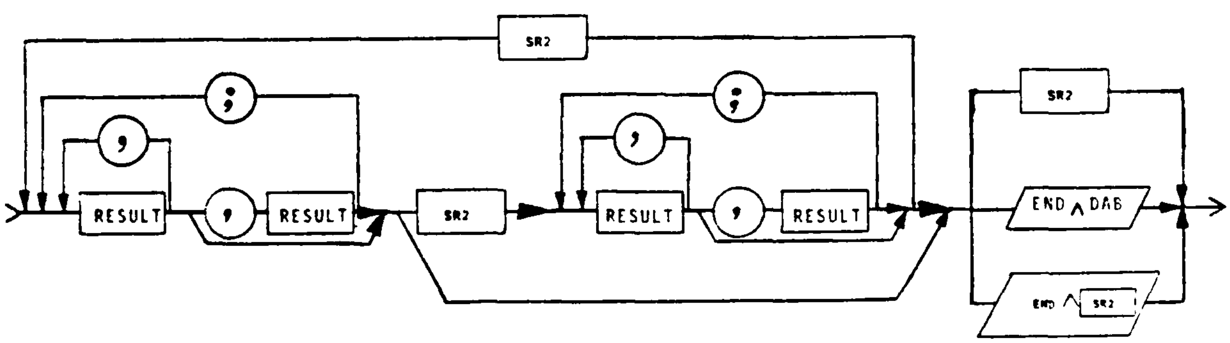


Figure 21B Separator Usage and Hierarchy Rules

5.2.2 Alternate Measurement Message Construction

This Recommended Practice does not define the mixing of program and measurement message units. The occasion may arise when measurement results from one device need to be transmitted for "processing" to another device. In this case measurement result(s) may be formatted according to the program message syntax constructs as defined throughout Section 6.

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6. PROGRAM MESSAGES

Instrumentation devices are called upon to perform many different tasks. This process of performing different tasks requires changes in the basic configuration of the device in preparation for performing the basic measurement or stimulus task. A device might be required to change operating mode, measurement range, or output mode, for example. Receipt of program instructions effect the necessary changes. The specific content of this data is device-dependent, however the organization or general format of these application dependent messages can be structured in a way common to many devices. The purpose of this Section is to establish a set of recommended practices for the format of program messages such that information interchange among independently designed devices is achieved at the highest possible level.

6.1 Program Message Overview

The individual syntax diagrams defined throughout Section 4 may be used to construct and assemble specific program data messages suited to unique applications. A generalized form of typical program messages is given in Figure 22 to introduce the normal flow of data fields, the "format" of the message. The reader is cautioned not to design to this diagram, it serves only to introduce the general flow of information.

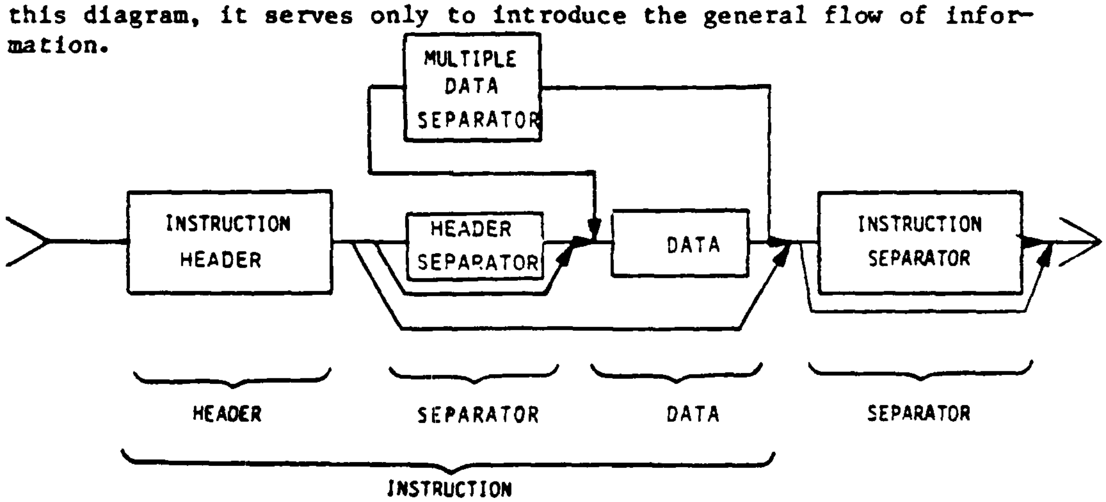


Fig. 22 GENERAL FORM: PROGRAM MESSAGE

The combination of a header, under special conditions a separator, and the instruction data itself form what is termed a program instruction. This is equivalent to a single message unit: the instruction is processed as a unit. Some form of separator is then used to distinguish this instruction from the next one. The instruction header field for program messages is mandatory. The optional header separator/data pair is denoted by the bypass path around these elements.

6.2 PROGRAM MESSAGE FORMATS

This clause sets forth the explicit syntax for a common set of program messages in a way considered to be relatively device and application independent. The specific content of each data field, at the lowest level (e.g., semantic meaning of the letter P), is beyond the scope of this document. Figures 23 A/B set forth the preferred syntactic construction of four different types of program instructions identified as digit data, numeric data, string data, and block data. Either Figure 23 A or Figure 23 B are to be viewed as a SINGLE program message or instruction. Many real applications, of course, require a series of program instructions. A subsequent diagram will indicate the method(s) available to achieve a variety of more complex messages.

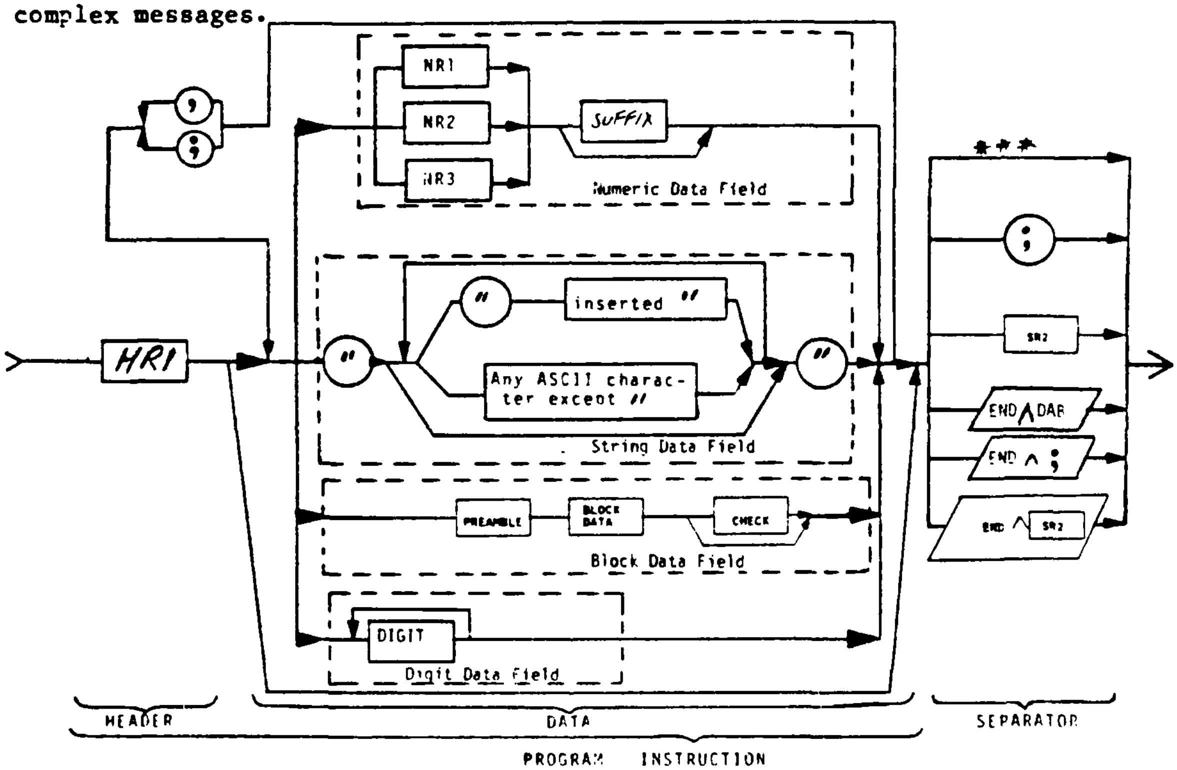


Figure 23A, Program Message Syntax Diagram

*** WARNING: any data field ending with an alpha character requires an unambiguous means of separation.

The syntax shown in Figure 23A is simpler than that shown in Figure 23B. A header separator is not used and it is possible to bypass the message separator. This is made possible by limiting the header to the alpha (HR1) characters only. The main focus

of this type of syntax diagram is to facilitate machine-to-machine communication and to facilitate simplicity in the programming of devices. The latter can be achieved by a high degree of correlation between front panel control markings and the content of program messages. The resultant instructions are more compact and less human readable than those produced by Figure 23B.

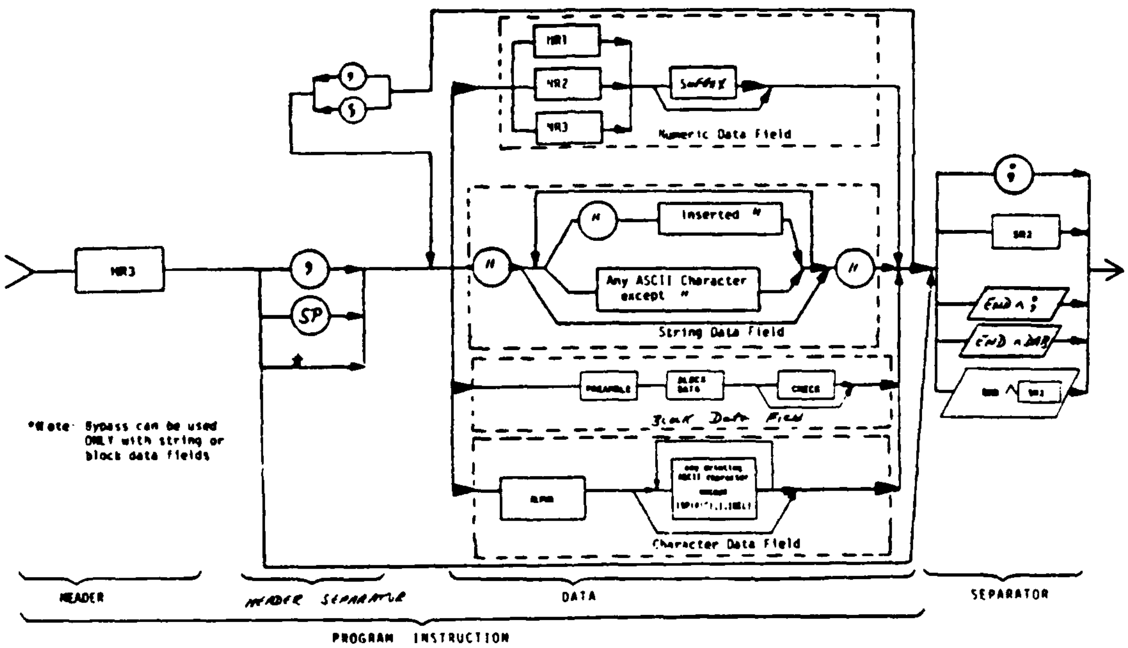


Figure 23A, Program Message Syntax Diagram

Each data field in Figure 23B is explicitly separated. This permits the content of the header field to contain non-alpha characters. Likewise the data field can now incorporate a character data field. Use of the space as a header delimiter permits the generation of messages more oriented toward human readibility. The use of special characters within the header and the character data field permits duplication of similar characters located on the front panel (e.g., VOLTS/DIV, TRIG, AUTO). Possible similarities between program instruction and actual instrument operation can facilitate a self-documenting program. The more human like instructions derived from Figure 23B will require, in general, more sophisticated parsers.

6.2.1 Program Message Construction

These guidelines and recommendations are provided to facilitate the construction of program messages intended for the highest level of interchange possible between independently designed devices.

6.2.1.1 General

- To accommodate a wide variety of devices the program message may contain any number of DABs.

- The DABs are sent most significant DAB first for numeric data.

- Program messages are normally input to a device. At times it is useful to output a program message for storage in some external device and subsequent recall to the originating device. Figures 23A and 23B may be considered as useable in this operational mode.

6.2.1.2 Header Field

It is MANDATORY that one of the header data fields be used in each specific program instruction.

- For Fig 23B, the HR field should be as short as possible, contain alpha characters only, and shall be unique for each individual message function.

6.2.1.3 Data Field

6.2.1.3.1 Numeric Data

- Use of the alpha suffix permits an instruction to be written and read in normal engineering units. For example, the message CF123.45KHZ establishes a center frequency of 123.45 kilohertz where CF is the header and KHZ the suffix.

6.2.1.3.2 String Data

- String data is intended where the message is to be displayed for human interpretation as on a printer, plotter, or display unit.

- The ability to carry any ASCII 7-bit character enables the message to contain non-printing characters and thus messages can be readily formatted for ease of human interpretation.
  Example: "CONNECT PROBE TO TEST POINT #1"

6.2.1.3.3 Block Data

- Block data fields are intended to be used where the message is of extended length.

- Block data supports relatively transparent data transmission and thus provides for the capability of sending binary data messages.

- To increase the data integrity for long message lengths, two alternate check means are provided. The rationale for the use of each check method is given in Clause 4.3.2.3.3.

  Example: #S 01000010 11100000 00000000 00000000
  (These four bytes in binary notation following the preamble represent the number 1.75E+06 in single floating point notation, see Appendix E)

- Designers should consider the impact of buffer size and availability and not assume that recipients of long records will be capable of accepting such records automatically.

6.2.1.3.4 Character Data

- The character data field permits the use of human oriented instructions. It is allowed only with Figure 23B.

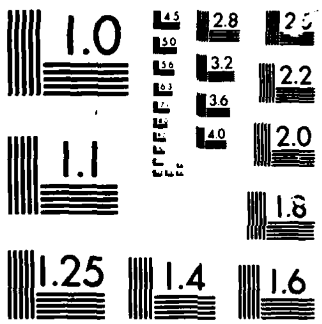
  Example: DISPLAY ON or DISPLAY OFF where DISPLAY is the header, ON and OFF are character data fields.

6.2.1.3.5 Digit Data

- Use of an HR1 field followed by one or more digits provides an abbreviated way to program a specific function (e.g., range R3). This method of programming allows equivalent front panel switch positions (e.g., high, medium, low) to be selected where precise numeric values are not required.

  Example: R2L1
  This example illustrates a simplified program instruction for "range 2" (10 volts), "level 1" (level off)
- Allowed only in Figure 23A.

AD-A167 022 RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN VOLUME 2 2/4
APPENDICES (PHASE..(U) PRATT AND WHITNEY WEST PALM
BEACH FL GOVERNMENT PRODUCTS DIV.. J S CARGILL ET AL.
UNCLASSIFIED OCT 81 P/W/GPD-FR-15175 F/G 14/2 NL



MICROCOP CHART

6.2.1.4 Separator Fields

Figures 23C1, 23C2, and 23C3 provide definition for three basic program instruction formats. Their purpose is to specify the manner in which more complex program instruction messages and sequences can be constructed and organized. Each diagram defines an orderly and consistent relationship among the several available separator types. Each individual syntax diagram may, in turn, be re-entered by looping back from rightmost exit to leftmost entrance with one exception. When an END message separator (i.e. SR3) is encountered the diagram is no longer re-entrant. The three syntax diagrams of Figures 23C provide substantial flexibility for the construction of program instructions.

It is recommended that a device's hierarchical separator capabilities be explicitly defined in the relevant product documentation to facilitiate use of the product in system configurations. Appendix B provides further guidance in this matter.

Specific requirements and guidelines are as follows;

- Each instruction shall be terminated with one of the separators identified in either Figure 23A or Figure 23B.

- It is preferred that, within a device, only ONE hierarchical diagram be used (i.e., 23C1 or 23C2 or 23C3).

- To achieve the more English-like instruction capability defined in Figure 23B, the |SP| is used as a special header separator in Figure 23C3. The reader is cautioned to consider the impact of this implementation as the use of |SP| no longer has a univeral meaning. A given product in a specific operating mode shall use only one of the header separators (i.e., |,| or |SP|).

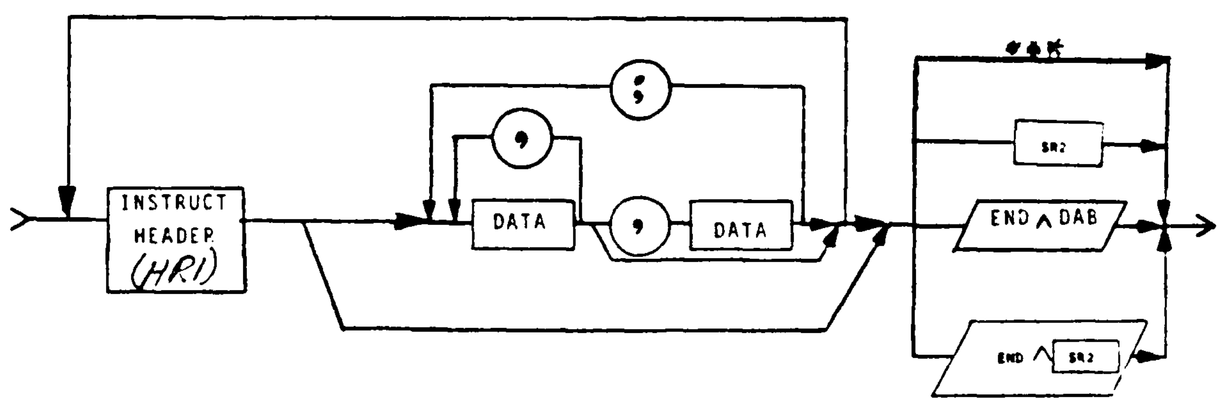
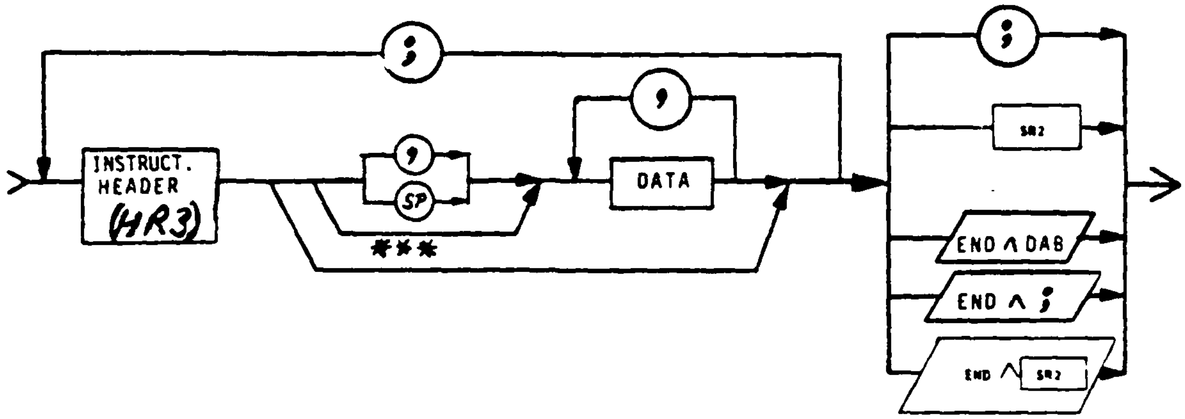
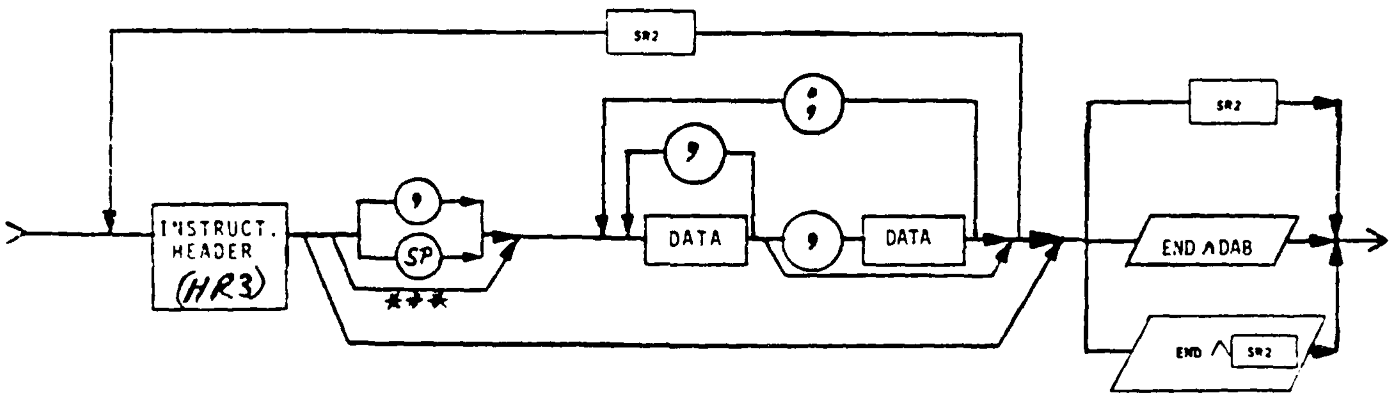


Figure 23C1 Separator Usage and Hierarchy Rules
(applies for use with Figure 23A only)

****WARNING: Any data field ending with an alpha character requires unambiguous means of separation (e.g. set, cal, test). +





Figures 23C2 and 23C3 Separator Usage and Hierarchy Rules
(apply to Figure 23B only)

**** Warning: Any data field ending with an alpha character requires an unambiguous means of separation.

7. STATUS MESSAGE

IEEE Standard 488 defines both serial and parallel means for sending status messages. This Section defines further the structure of a single status data byte sent during a serial poll. Parallel poll message structure is specified in the Standard.

A status message may be sent from a device with an STB message (DIO1...6, DIO8) in response to a serial poll sequence when the device is in the SPAS state. The principle purpose of the STB message is to present critical summary and detailed status to the controller-in-charge. Summary status means the logical OR of detailed status within the same category, e.g., if more than one abnormal condition exists. A wide variety of device-dependent internal states and conditions may be carried by STB messages and therefore a complete data structure and code assignment is not feasible. A degree of compatibility between devices can be accommodated when the lines DIO1...6 are used according to the conventions in this Section. The RQS message (DIO7) is sent concurrent with the STB message.

7.1 Summary Status Conditions

DIO6 sent true reports a summary status condition associated with abnormal operation of a device. Typical use would include internal error conditions within the device functions, erroneous program message sent to a device, incomplete or erroneous measurement message, limit or alarm conditions. DIO6 sent false reports normal operation is occuring or has been completed (e.g., currents within limits).

7.2 Busy/Ready Condition

> Note: At one time it was considered appropriate to reserve DIO5 to indicate the fact that a device was either "busy" completing its assigned task or "ready" to start another one. In this case, the "ready" message could indicate either ready to have "data read out" or ready to "start new operation". The meaning of "ready" could be ambiguous. The demand for additional device-dependent status message code space led to the recommendation of clause 7.3. If it is meaningful to indicate busy/ready messages, then use of DIO5 is the appropriate signal line.
> IEC Publication 625-2 specifies DIO5 as a busy/ready data bit.

7.3 Additional Conditions.

DIO1-5 and DIO8 are available for designer assignment to report either additional summary status or more detailed status. The six bits (DIO1-DIO5 and DIO8) may be used in any manner to report device-dependent conditions.

7.4 General Guidelines

The preferred code assignment for the STB messages are given in Table III.

Messages	RQS	STB			
Logical Value	DIO7	DIO8	DIO6	DIO5	DIO4-DIO1
1	Requested Service	X	Abnormal	X	X X X X
0	Not Requested Service	X	Normal	X	X X X X

X = device-dependent code assignment

Table III: Status Message Structure and Code Assignment

The content of the STB message sent on DIO1-6 is free to change between STB message transfers as the internal device functions change. However, the coding of the messages for a given device is not permitted to change. Status message as used herein refers to a single STB message byte as defined by IEEE Standard 488. If more detailed status data is required, then device-dependent means are to be used.

The conventions of this Section are intended to be used where device-dependent requirements do not dictate otherwise.

If a device has one and only one reason for requesting service, then the status for this reason may be indicated on the RQS bit.

8. DISPLAY MESSAGES

This document does not contain a specific recommendation for the syntax of data uniquely utilized for display purposes. Both the program and measurement messages, however, can be used for display purposes. The character and string data types are particularly useful for this purpose for which the specifications in Sections 5 and 6 are considered useful.

Display messages are intended for device input or output where human interpretation is important. Display messages should follow Section 5 specifications for measurement messages as far as possible.

9. DATA SHIFT TECHNIQUES

Some applications require that DABs, data bytes input to a device, be interpreted as one type of data during a given series of message unit transfers and as another type of data during subsequent message unit transfers. Sections 5 and 6 of this Recommended Practice clearly identify several different data types. The explicit means of intermixing different data types (e.g., program instructions and measurement results) is beyond the scope of this document. However, Clause 5.2.2 gives some general guidelines.

IEEE Standard 488 (Clause 5.5) indicates one available resource, multiple listen addresses, to facilitate a given device's reception of two (or more) different data types.

The designer may utilize unique device-dependent coding to select between different data types while that device is a single addressed listener. Care must be exercised to avoid ambiguous code assignments. Assignment of these special "shift" codes may reduce the remaining code space available for measurement, program, or display data.

10. DATA CODING

10.1 Recommended Code

The ANSI X3.4-1977 ASCII 7-bit code is the recommended data representation code for communication of device-dependent messages as described throughout Sections 5 & 6. The ASCII 7-bit code is shown in Table IV.

10.2 Hexadecimal Code

The ASCII 7-bit code set may be used to represent hexadecimal data for communication of selected device dependent messages. The code set shall be as follows:

0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F

10.3 Octal Code

The ASCII 7-bit code set may be used to represent octal data for communication of selected device dependent messages. The code set shall be as follows:

|0|1|2|3|4|5|6|7|

10.4 Floating Point Coding

The coding techniques for floating point are described in Appendix E.

b_4	b_3	b_2	b_1	Row \ Column	0 ($b_7b_6b_5$ = 000)	1 (001)	2 (010)	3 (011)	4 (100)	5 (101)	6 (110)	7 (111)
0	0	0	0	0	NUL	DLE	SP	0	@	P	`	p
0	0	0	1	1	SOH	DC1	!	1	A	Q	a	q
0	0	1	0	2	STX	DC2	"	2	B	R	b	r
0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
0	1	0	0	4	EOT	DC4	$	4	D	T	d	t
0	1	0	1	5	ENQ	NAK	%	5	E	U	e	u
0	1	1	0	6	ACK	SYN	&	6	F	V	f	v
0	1	1	1	7	BEL	ETB	'	7	G	W	g	w
1	0	0	0	8	BS	CAN	(	8	H	X	h	x
1	0	0	1	9	HT	EM	)	9	I	Y	i	y
1	0	1	0	10	LF	SUB	*	:	J	Z	j	z
1	0	1	1	11	VT	ESC	+	;	K	[	k	{
1	1	0	0	12	FF	FS	,	<	L	\	l	|
1	1	0	1	13	CR	GS	-	=	M	]	m	}
1	1	1	0	14	SO	RS	.	>	N	^	n	~
1	1	1	1	15	SI	US	/	?	O	_	o	DEL

Table IV ASCII 7-bit Code (Note: NL code is identical to LF code)

11. CODE ELEMENTS RELATED TO SIGNAL-LINES

11.1 General Coding Rule

In general, the least significant bit of a multi-bit code transferred concurrently across the interface is placed on the DIO line with the lowest number. An 8-bit binary code shall utilize DIO1 through DIO8 to represent bits 2^0 through 2^7. It is preferred that for a single data byte the data byte be right justified (e.g. a 5-bit code utilizes DIO1 through DIO5 respectively to represent bits 1 through 5). Unused signal lines should be set false.

11.2 ASCII 7-Bit Code Element Relationships

The ASCII 7-bit code bits shall be assigned to the DIO signal lines as shown in Table V. DIO8 is set false if it is not used for any specific purpose (e.g. DAB or parity).

Column of ASCII 7-bit Code		b7	b6	b5	b4	b3	b2	b1
DIO line	DIO8	DIO7	DIO6	DIO5	DIO4	DIO3	DIO2	DIO1

TABLE V: Code/Line Relationship

12. ERROR DETECTION

The need for error detection capability within instrumentation systems varies significantly in relation to the nature of the noise environment, nature and importance of data carried on the interface, type of device function active at both data source and acceptor, and the overall system application.

The choice of which error detection technique should be used is application dependent; therefore a single method is not recommended. Several common techniques are as listed below, along with comments about their application.

12.1 Error detection "at the bit level"

12.1.1 A simple lateral parity bit on DIO8 to detect errors contained on DIO1-7 for the ASCII 7-bit code provides minimal means for error detection and requires minimal hardware. Parity check permits detection of a single error within the bit grouping of a byte. Multiple-bit errors within a byte may not be detected. Use of DIO8 as a parity bit is not preferred.

12.1.2 A longitudinal parity check bit on any given DIO line at the end of a data record may be used in the same way as the lateral parity check bit for the same purpose and results. See Clause 4.3.2.3.3 for guidance on the use of checksum techniques.

12.1.3 A cyclic redundancy check(CRC) is much more comprehensive* and assures a higher degree of error detection capability, see Clause 4.3.2.3.3 for CRC16 for details.

12.2 Error detection "at the message level"

12.2.1 An instrument receiving a programming command message can check the message for proper syntax so that all the data that is expected has the proper format. Commands not having the proper syntax should not be executed. Instead, a service request (SRQ) message should be generated and the status byte (STB) on the subsequent serial poll should indicate a syntax error.

12.2.2 An instrument receiving a programming command message can check the semantics of the message to see if they are meaningful and executable. For example, a power supply with a maximum output of 50 volts should not attempt to execute a command that tells it to output 500 volts. Instead, a service request should be generated and the status byte on the subsequent serial poll should indicate an execution error.

12.2.3 The types of errors listed in 12.2.1 and 12.2.2 above are generally human errors in programming instruments or controller generated commands which produce out of bounds conditions. The recovery from these errors normally involves human intervention and is beyond the scope of these recommended practices.

12.3 Error recovery is often a required capability in systems having error detection. Specific error recovery techniques are beyond the scope of this Recommended Practice. Two common approaches are retransmission of data received in error and use of forward error correction (e.g., Hamming codes).

Appendix A
MESSAGE FORMAT EXAMPLES: SYNTAX DIAGRAM USE

A1.0 General Comments

The conventions presented throughout this document provide the designer and user with a set of recommended formats for each different message type.

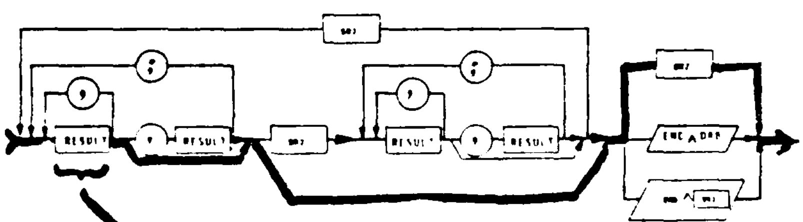
Rigid and mandatory message structures are considered to be too restrictive for broad general use. Typical formats for several different messages are given in this Appendix to illustrate the application of the recommended conventions. It is expected that individual product designs may deviate from the recommended conventions in special circumstances. Adherence to the recommended formats is encouraged strongly to increase the level of information interchange and compatibility among interconnected devices.

A1.1 Measurement Messages (per Fig. 21A and 21B)

A1.1.1 One voltage measurement of +10.002 VDC is taken on the 10 volt range and expressed in NR3 (exponential) notation. The numeric value is preceded by an alpha header to indicate the type (DC) measured result. The message is concluded with CRLF for one measurement result.

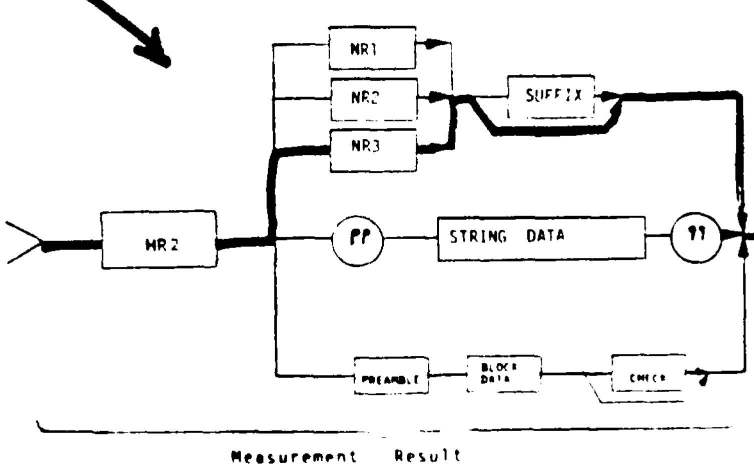
Measurement Result: DC+10002.E-03CRLF

Syntax Construction:



PASS 1
SEPARATOR CRLF

Fig. 21B



PASS 1
HEADER DC
DATA +10002.E-03

Fig. 21A

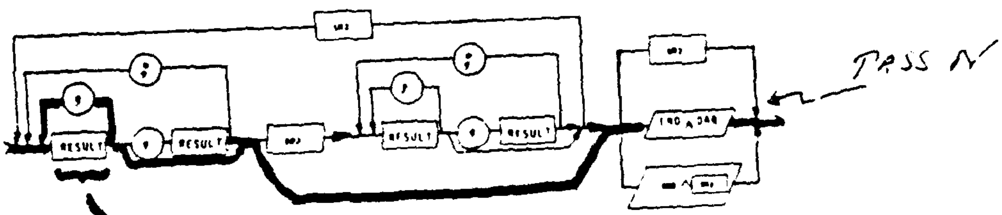
A1.1.2 A spectrum analysis is made over a specified frequency span yielding 1000 measurements expressed in NR2 notation and separated by commas (in this case the dBm units are implicit).

Measurement Results:

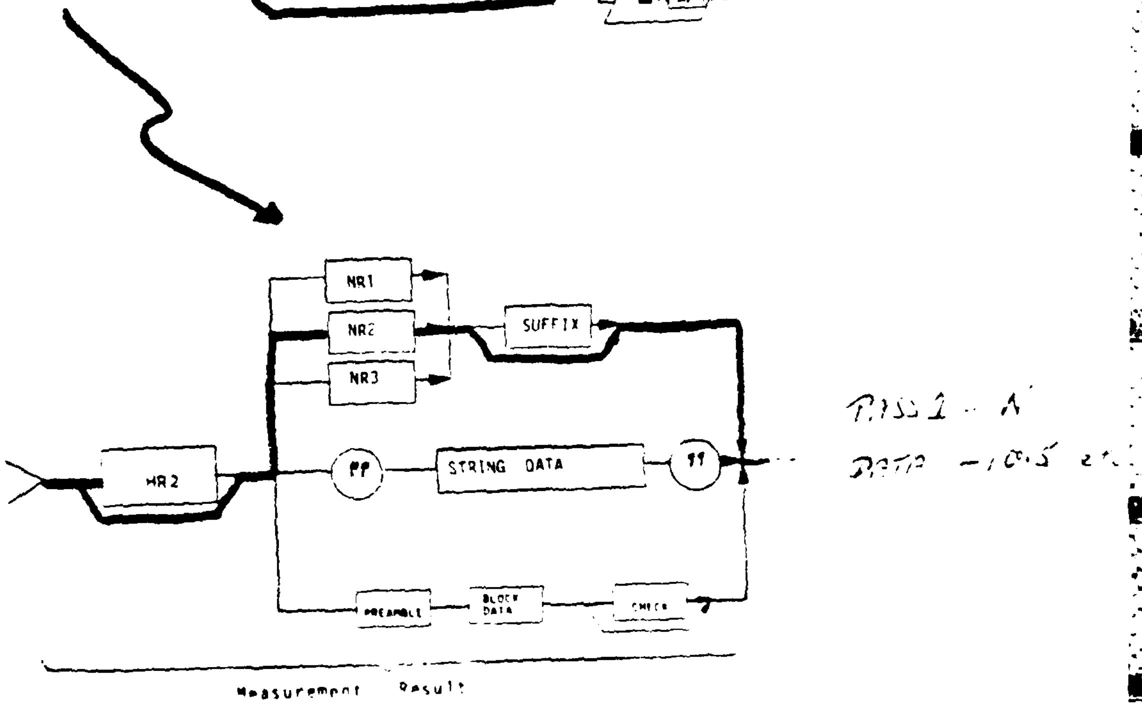
-10.5,-11.1,(...)-86.1,(...)-11.[1 ^ END]

NOTE: The (...) symbols do not appear in the actual message. They serve only to indicate additional data in this example. [ ] indicates END sent concurrent with last byte |1| of "result".

Syntax Construction:



1964.02 Fig. 21B



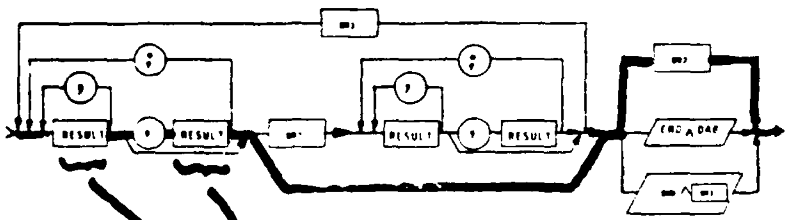
1964.04 Fig. 21A

A1.1.3 A frequency counter with two channels (A and B) measures frequencies of 4.23 kHz and 2.60 kHz.

Measurement Result:

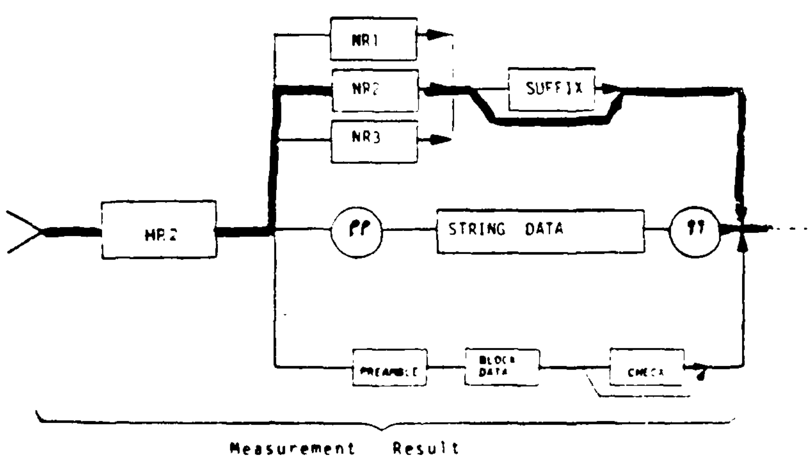
AFKHZ4.23,BFKHZ2.60<u>NL</u>

Syntax Construction:



PASS 1 & 2

Fig. 21B



PASS 1
AFKHZ4.23

PASS 2
BFKHZ2.60

Fig. 21A

A1.1.4 A DVM takes a measurement of 10.002 V DC and sends it in NR2 notation.

Measurement Result:

VOLTS 10.00[2^END]

Syntax Construction:

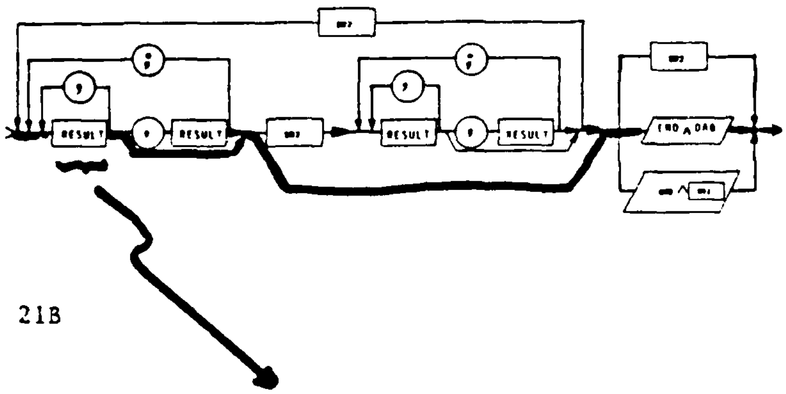


Fig. 21B

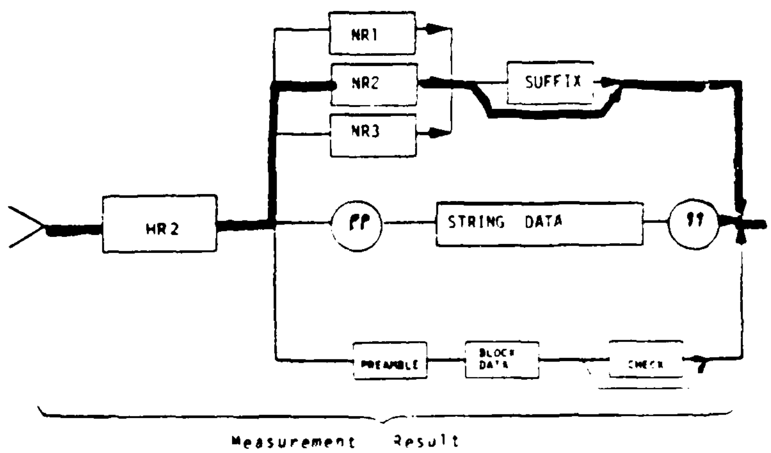


Fig. 21A

A1.1.5 An oscilloscope sends a waveform identification as a string value and the waveform itself (1024 data points) as a block value (requires two passes through the syntax diagram separated by |,|)

Measurement Result: WAVEFORM "CHANNEL 1",#BLLD...DDDC[C^END]

where;	L =	0100 0100	(length byte 1) (data field even, CRC used)
	L =	0000 0010	(length byte 2) (total length 1026 bytes)
	D =	0110 0000	(point 1)
	: :		:
	D =	0110 1000	(point 1022)
	D =	1011 0000	(point 1023)
	D =	1000 1101	(point 1024)
	C =	xxxx xxxx	(CRC check byte 1)
	C =	xxxx xxxx	(CRC check byte 2)

Syntax Construction:

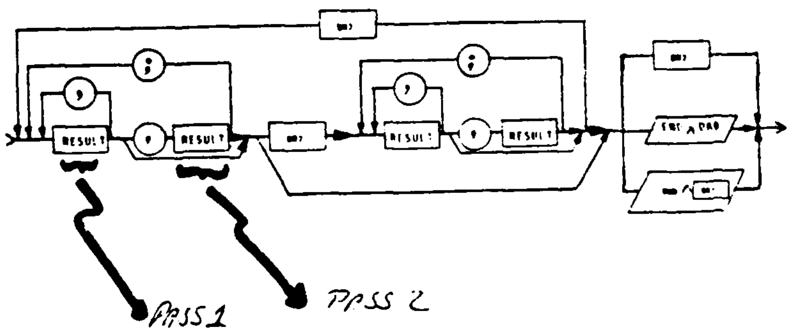


Fig. 21B

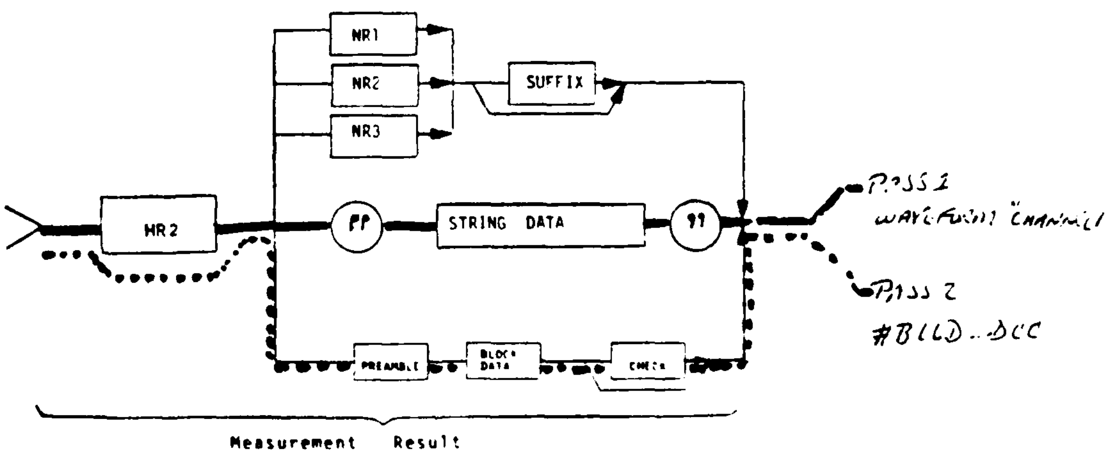


Fig. 21A

A1.2 Program Messages (per Fig. 8A and 8C1)

A1.2.1 A voltmeter is programmed to measure DC volts on the 10 V range(R4) upon receipt of an internal trigger(T1) and output the measured quantity once the program(P) is executed. The DC function (F0) is performed using mode 3(M3)

Program Instruction(s):

Case A: F0R4T1M3P

Case B: FCTN0RNGE4TRIG1MODE3PROG

Syntax Construction:

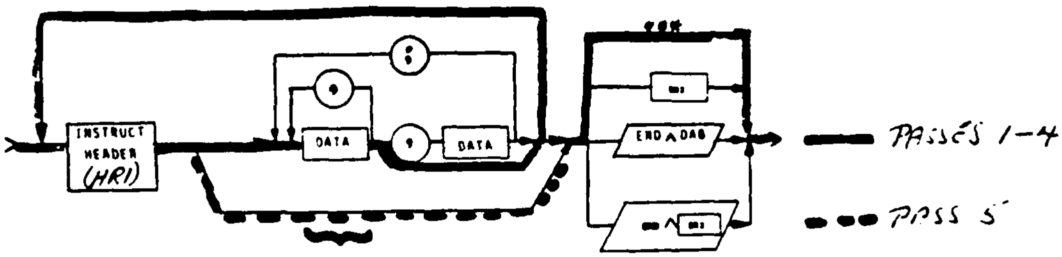


Fig. 23C1

Pass	Case A Header	Case A Data	Case B Header	Case B Data
1	F	0	FCTN	0
2	R	4	RNGE	4
3	T	1	TRIG	1
4	M	3	MODE	3
5	P		PROG	

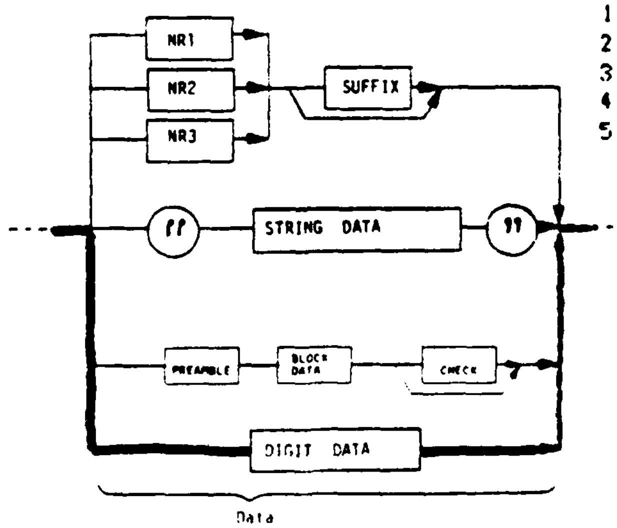


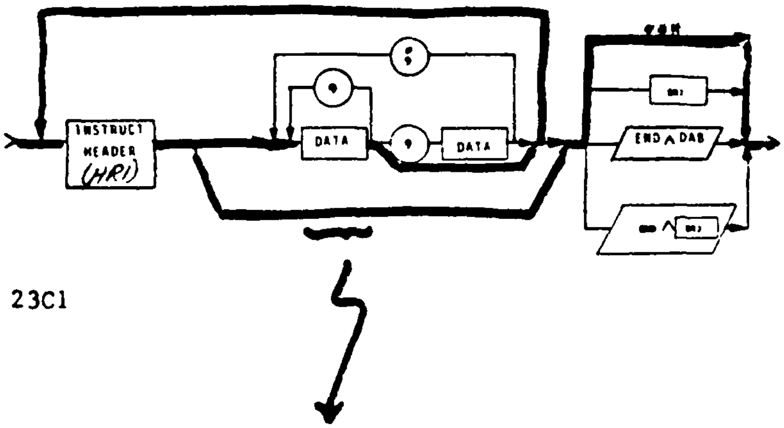
Fig. 23A

A1.2.2 A spectrum analyzer is programmed to make and store 1000 amplitude measurements using the A3 mode of storage and display. These measurements are to be centered about a frequency (CF) of 12.345 MHz over a span (SP) of 1000 Hz. The take sweep (TS) command causes this measurement sequence to be executed once:

Program Instruction:

CF12.345E+06HZSP1000HZTSA3

Syntax Construction:

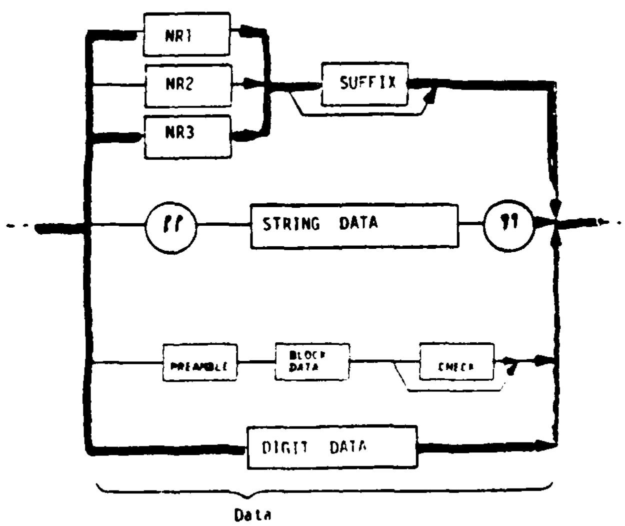


PASSES 1, 2, 4

PASS 3

2038.1 Fig. 23C1

Pass	Header	Data
1	CF	12.345E+06HZ
2	SP	1000HZ
3	TS	
4	A	3



PASS 2

PASS 1

PASS 4

2038.3 Fig. 23A

A1.2.3 A dual power supply is programmed to deliver both + and - 5.25V at current limits of 120MA and 60MA respectively.

Program Instruction:

VI+5.25,120E-03;-5.25,60E-0[3^END]

Syntax Construction:

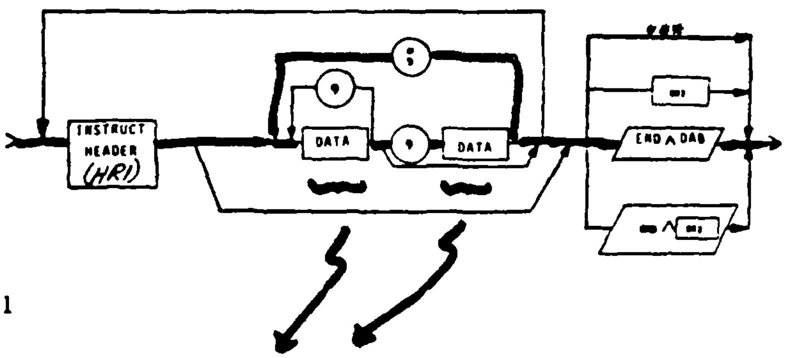
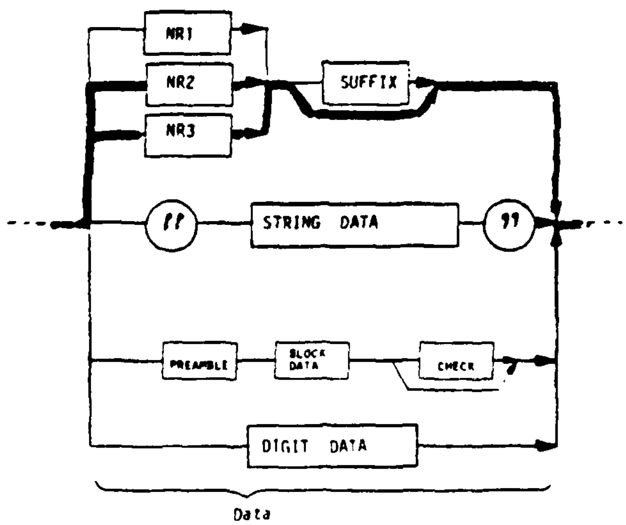


Fig. 23C1



PASSES 1, 3
PASSES 2, 4

Fig. 23A

Pass	Message
1	+5.25
2	120E-03
3	-5.25
4	60E-03

(NOTE: SR3 (3^END) is used as a separator)

A1.3 Program Messages (per Fig. 8B and 8C2, 8C3)

A1.3.1 Set a DVM to 10 volt range:

Program Instruction:

RANGE 10[V^END]

Syntax Construction:

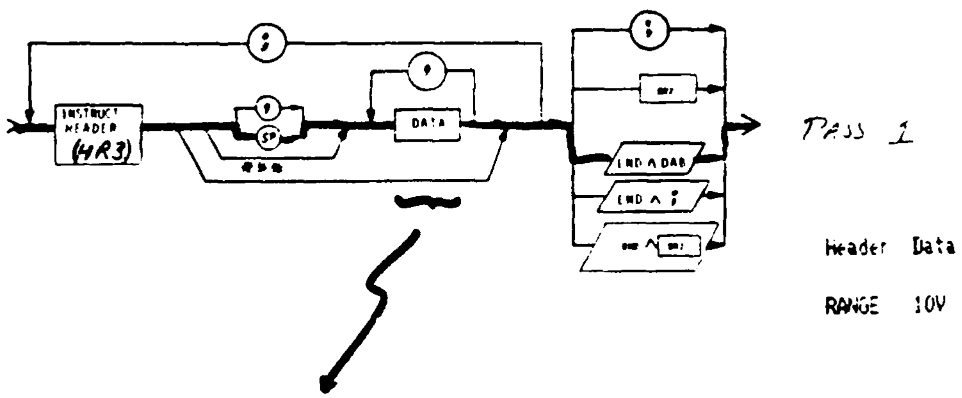


Fig. 23C2

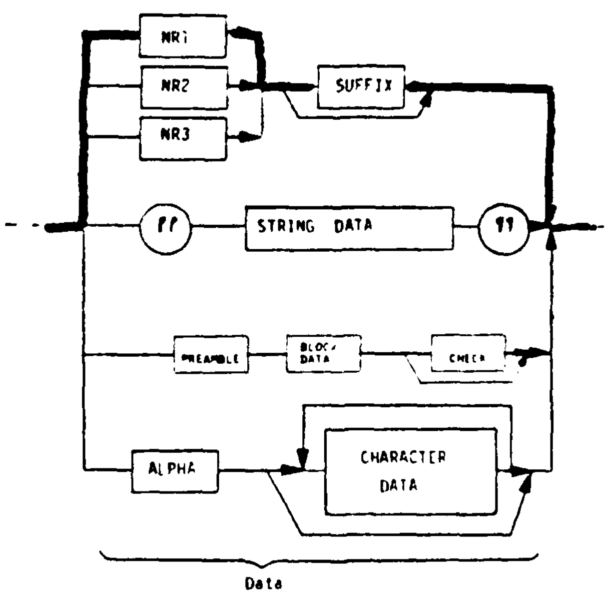


Fig. 23B

A1.3.2 Set a power supply to 10.5 volts with the output on (requires two passes through syntax diagram).

Program Instruction:

VOLTS 10.5;OUTPUT ON<u>CRLF</u>

Syntax Construction:

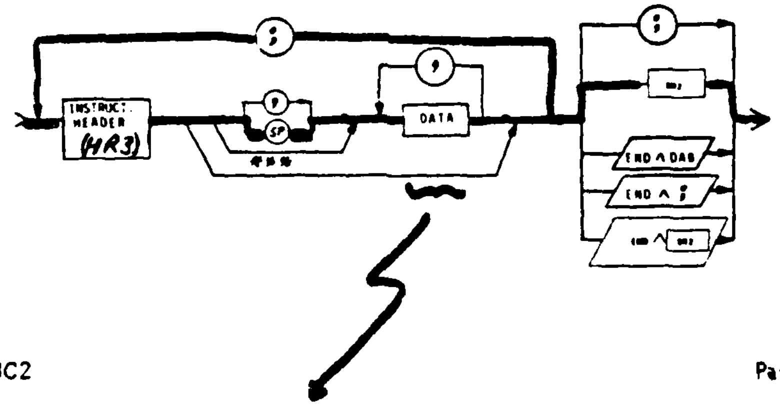
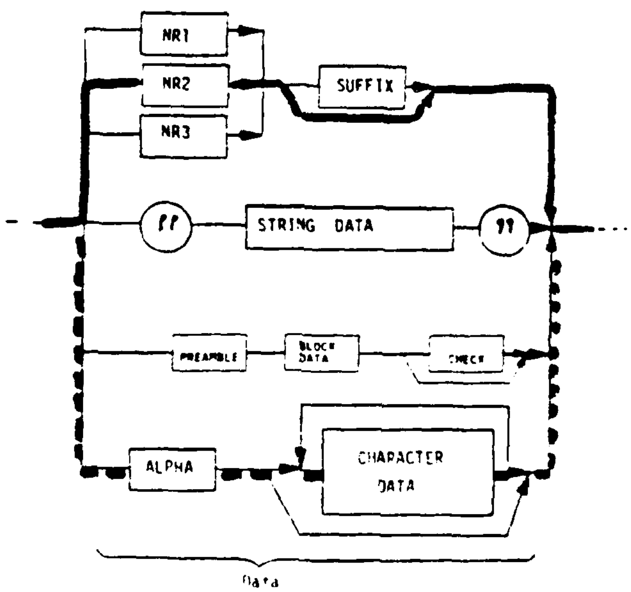


Fig. 23C2

Pass	Header	Data
1	VOLTS	10.5
2	OUTPUT	ON



PASS 1

PASS 2

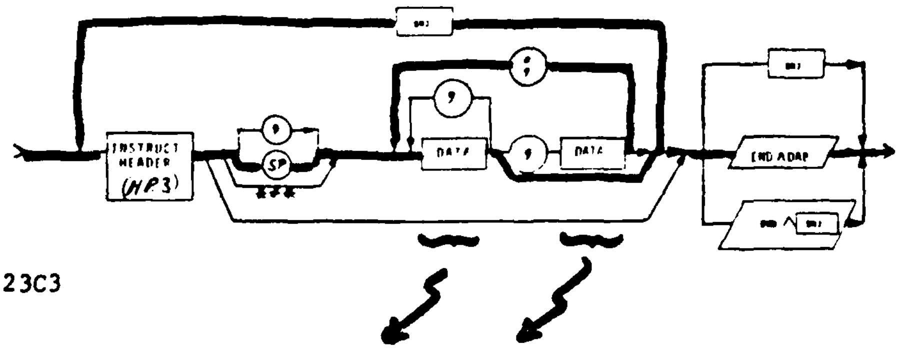
Fig. 23B

A1.3.3 Have a plotter draw a square and label it "DEMO".

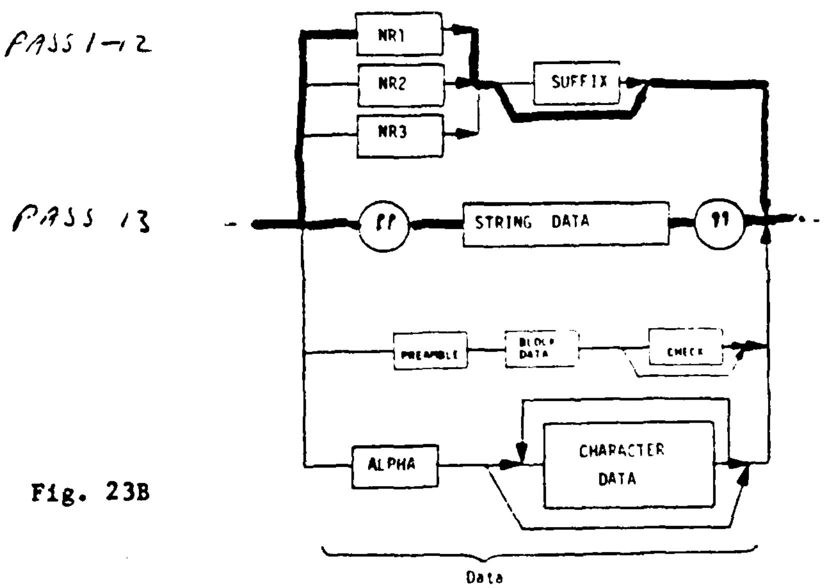
Program Instruction:

```
MOVE 10,10NL RAW 90,10; 90,90; 10,90; 10,10NLMOVE 40,0NL
LABEL "DEMO["^END]
```

Syntax Construction:



2082.1 Fig. 23C3



Pass	Header	Data
1	MOVE	10
2		10
3	DRAW	90
4		10
5		90
6		90
7		10
8		90
9		10
10		10
11	MOVE	40
12		0
13	LABEL	"DEMO"

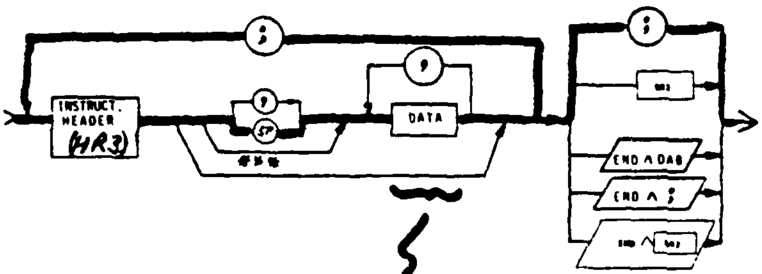
2082.3 Fig. 23B

A1.3.4 A plotter sends the coordinates of its pen position.

Program Instruction:

XPOS 53.68;YPOS 98.62;

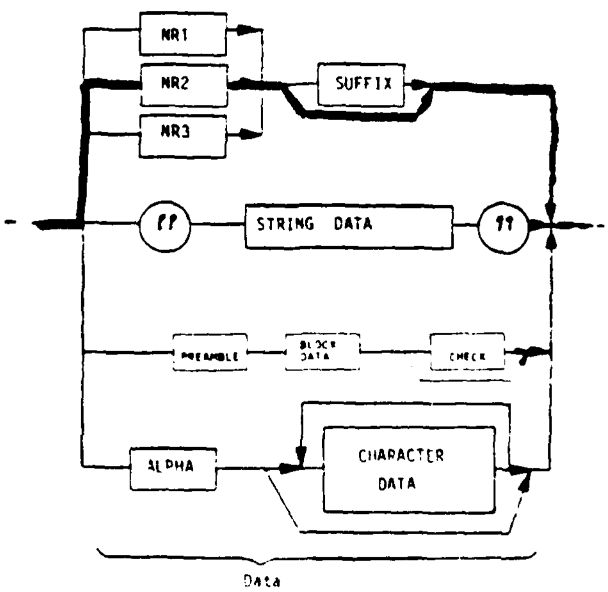
Syntax Construction:



2093.1 Fig. 23C2

Pass	Header	Data
1	XPOS	53.68
2	YPOS	98.62

PASSES 1, 2



2093.3 Fig. 23B

APPENDIX B
FORMAT CAPABILITY IDENTIFICATION CODES

B1 General Comments

Sections 5 and 6 of this Recommended Practice define the syntactical structure of two broad types of messages for general use in the design and application of instrumentation systems; measurement messages and program messages. It is helpful to have products using this Recommended Practice employ the format capability codes (mnemonics) listed in Section B2 as a means to assist the user in identifying the specific syntactic structures employed within a particular product. The mnemonic representation of specific formats used by a product may be placed on that product's data sheet, operating manual and, where feasible, on the product itself.

B2 Format Capability Identification Codes

The Table below lists those data fields and message unit constructs (particularly the hierarchial message constructs) and the assigned mnemonics considered to be useful in identifying product message format capability. Sections 5 and 6 of this Recommended Practice define the hierarchial message structures used when multiple message units are assembled together. Mnemonics for these constructs are also given.

Data Field Elements	Mnemonic
Numeric data field	
Implicit point	NDR1
Fixed point	NDR2
Scaled (floating point)	NDR3
String data field	STDF
Character data field	CHDF
Block data field	
Binary Block	BDFB
Text Block	BDFT
Single Precision	BDFS
Double Precision	BDFD
Extended Precision	BDFX
Hexadecimal	BDFH
Octal	BDFO

Digit data field DIDF

Message Unit Formats and Hierarchial Separators:

Measurement Messages
- o syntax per Figures 21A and 21B MM1

Program Messages
- o syntax per Figures 23A and 23C1 PM1
- o syntax per Figures 23B and 23C2 PM2
- o syntax per Figures 23B and 23C3 PM3

In addition, it is considered useful to identify the set of explicit separators used with the product. Identification of the intra-message separators and EXIT separators is useful for both the messages sent and received, as appropriate.

B3 Application of Format Capability Codes

The mnemonic codes presented in this appendix allow concise expression of the message syntax used by that device. IT IS NOT EXPECTED THAT ALL POSSIBLE COMBINATIONS OF A DEVICE'S MESSAGE SYNTAX CAPABILITY CAN BE IDENTIFIED IN SHORT MNEMONIC FORM. It is however, recommended that the operating manual describe the message syntax capabilities in detail such that assembly and use of the product is *facilitated*.

B3.1 Measurement Message Examples:

Measurement message examples given in Appendix A are further illustrated here by the addition of the relevant format capability codes;

```
   Message                      Format   Capability Codes
   -------                      ------------------------
DC+10002.E-03CRLF                NDR3     MM1    CRLF

-10.5,-11.1,-86.[1^END]          NDR2     MM1    |,| END

AFKHZ4.23,BFKHZ2.60NL            NDR2     MM1    |,|NL

VOLTS 10.00[2^END]               NDR2     MM1    END

WAVEFORM "CHANNEL 1",
  #BLLDDDDC[C^END]               BDFB     MM1    |,| END
                                 STDF
```

B3.2 Program Message Examples;

Program message examples given in Appendix A are further illustrated here by the addition of the relevant format capability codes;

Message	Capability Code(s)		
FOR4T1M3P	NDR1	PM1	
FCTNORNGE4TRIG1MODE3PROG	NDR1	PM1	
CF12.345E+06HZSP1000HZTSA3	NDR3 NDR1	PM1	
VI+5.25,120E-03;-5.25,60E0[3^END]	NDR2 NDR3	PM1	|,|;| END
RANGE 10[V ^ END]	NDR1	PM2	END
VOLTS 10.5;OUTPUT ONCRLF	NDR2 CHDF	PM2	|;|CRLF
MOVE 10,10NLDRAW 90,10; 90,90; 10,10NLMOVE 40,0NLLABEL "DEMO["^END]	NDR1 STDF	PM3	|,|;| END|NL|

Appendix C

Preferred SI Units and Multipliers

C1. General Comments

The preferred SI units and multipliers are representative of the information presented in IEC Publication 27-1 and 27-2 "Letter Symbols to be Used in Electrical Technology" and in ASCII 1000-1973 "SI units and Recommendation for Use of Their Multiples" and ASCII 2955-1974. "Information Processing - Representation of SI and other Units for use In System with Limited Character Sets" (# per ASCII 2955 revision now under consideration).

NOTE: THE SI UNITS AND MULTIPLIERS LISTED BELOW ARE TO BE CONSIDERED AS GENERAL RECOMMENDATIONS AND GUIDELINES ONLY. THE ASSIGNMENT OF ABSOLUTE SEMANTIC MEANING TO SPECIFIC CHARACTERS IS BEYOND THE SCOPE OF THIS DOCUMENT. THE DESIGNER SHOULD SELECT CHARACTERS IN SUCH A WAY AS TO AVOID AMBIGUITY OF MEANING.

C1.1 Base SI Units

	Common Usage	Upper Case
metre	m	M
kilogram	kg	KG
second	s	S
ampere	A	A
kelvin	K	K
mole	mol	MOL
candels	cd	CD

C1.2 Derived SI Units

	Common Usage	Upper Case
hertz	Hz	HZ
newton	N	N
pascal (#)	Pa	PAL
joule	J	J
watt	W	W
volt	V	V
farad	F	F
ohm	Ω	OHM
siemens	S	SIE
weber	Wb	WB
tesla	T	T
henry	H	H
lumen	lm	LM
lux	lx	LX
bel	B	B

C1.3 Other Units

	Common Usage	Upper Case
grade (angle)	g(s)*	GON
degree (angle)	°(s)	DEG
minute (angle)	′(s)	MNT
second (angle)	″(s)	SEC
litre	l	L
are	a	ARE
minute (time)	min	MIN
hour	h	HR
day	d	D
year	a	ANN
gram	g	G
tonne	t	TNE
bar	bar	BAR
poise	P	P
stokes	St	ST
electronvolt	eV	EV
Degree Celsius	°C	CEL
atomic mass unit	u	U

*(s) indicates symbol is used in the right superscript position (like an exponent)

C1.4 Multipliers

Multipliers	Factor by which Unit is Multiplied	International Symbol (Common Use Symbol)	Representation for Simple Character Sets
eta **	10^{+18}	E	EX
peta **	10^{+15}	P	PE
tera	10^{+12}	T	T
giga	10^{+9}	G	G
mega	10^{+6}	M	MA ****
kilo	10^{+3}	k	K
hecto	10^{+2}	h	H
deca	10^{+1}	da	DA
deci	10^{-1}	d	D
centi	10^{-2}	c	C
milli	10^{-3}	m	M
micro	10^{-6}	u	U
nano	10^{-9}	n	N
pico	10^{-12}	p	P
femto	10^{-15}	f	F
atto	10^{-18}	a	A

**** Use of M in place of MA is the preferred practice if no textual confusion results.

** Per ISO 2955

APPENDIX D

Listen Mode Recommendations

D1 General Comments

Devices are expected to send device-dependent data (in TACS) according to the message formats defined throughout this document. Both instruments and controllers can however, improve the level of information interchange by listening "forgivingly" when in LACS. To listen forgivingly, a device should accept not only messages that are in the exact formats specified in Sections 5 and 6, but also messages that may have minor variations of these format structures. Some of the likely variations are due to inadvertent human error and limited capability in some products to provide a variety of output formats resultant from cost or performance considerations (e.g., an instrument optimized for one single application but used in a totally different application).

D2 Specific Recommendations

In order to make the use of instruments and controllers more flexible in a variety of system applications and to promote the highest level of information interchange possible with IEEE 488 products, these recommendations are given with the idea of listening "forgivingly";

1. Numbers (i.e. NR1-NR3) having a ZERO value and negative sign should be accepted.

2. NR3 representations that do not have a signed exponent should be accepted.

3. If a device receives an NR that has greater precision than the device can handle internally, the device should "round-off" the value rather than truncate it.

4. Wherever feasible, HR and other data sent to a device as lower case alpha characters should be interpreted as the corresponding upper case characters. This capability makes a device, instrument or controller, easier to use where the sending device outputs either upper or lower case alphas as part of their ordinary operations.

APPENDIX E

E 1: Floating Point Representations

The block representations specified throughout Clauses 4.3.2.3, 5.2.1.3.3 and 6.2.1.3.4 reference means to express both single and double precision floating point numbers.

An IEEE draft standard is under consideration which addresses this subject and contains specific proposals for single and double precision representations as well as extended single-precision representation considered useful for application to IEEE Std. 488 compatible products.

E.2 Extracts from draft IEEE Floating-Point Arithmetic Std.

E2.1 BASIC FLOATING POINT FORMATS. Any nonzero real number may be expressed in "normalized floating point" form as $+/-2^{e*}f$, where e is the signed integer exponent and the significant digit field f satisfies $1 \leq f < 2$. The draft standard describes a machine representation of a finite subset of the real numbers based on this floating-point decomposition, and prescribes rules for arithmetic on them.

There are two basic formats, single and double precision that may be implemented in one of the combinations shown in Table E.1. Single is required since it is useful as a debugging precision and is efficient over a wide range of applications where storage economy matters.

A normalized nonzero number X in the single format has the form

$$X = (-1)^{S*}2^{E-127*}(1.F) \text{where}$$

S = sign bit
E = 8-bit exponent biased by 127
F = X's 23-bit fraction which, together with an implicit leading 1, yields the significant digit field "1.-".

The values 0 and 255 of E are reserved to designate special operands discussed in later sections; one of them, signed zero, is represented by E=F=0. Normalized nonzero single numbers can range in magnitude between $2^{-126*}1.000...00$ and $2^{127*}1.111...11$, inclusive.

The number X above is represented in storage by the bit string:

```
 ----------------------------------------
 | S |    E    |          F             |
 ----------------------------------------
```

This encoding has the special property that the order of floating point numbers coincides with the lexicographic order of their machine counterparts when interpreted as sign-magnitude binary integers, facilitating comparisons of numbers in the same format.

E2.2 EXTENDED FORMATS. To perform the arithmetic operations on numbers stored in the single and double formats, a system will generally unpack the bit strings into their component fields S,E, and F. Moreover, the leading significant bit will be made explicit, and perhaps the bias will be removed from the exponent.

The draft standard provides a way to exploit this unpacked format by admitting the optional single-extended format per Table E.2. If implemented at all, only single extended format should be provided.

Table E.1

BASIC FLOATING POINT FORMATS

	SINGLE	DOUBLE
Fields and widths in bits:		
S = Sign	1	1
E = Exponent	8	11
L = Leading bit	(1)	(1)
F = Fraction	23	52
Total Width	(1)+32	(1)+64
Sign:	+/-represent by 0/1 respectively	
Exponent:	biased integer	
Max E	255	2047
Min E	0	0
Bias of E	127	1023
Normalized numbers:		
Range of E	(Min E + 1) to	(Max E -1)
Represented number	$(-1)^{S} * 2^{E-bias} * (L.F)$	
Signed zeros:		
E	Min E	Min E
L	(0)	(0)
F	0	0
Reserved operands:		
Denormalized numbers:		
E	Min E	Min E
L	(0)	(0)
F	nonzero	nonzero
Represented number	$(-1)^{S} * 2^{E-bias} (L.F)$	
Signed ∞s:		
E	Max E	Max E
L	(0)	(0)
F	0	0
NaNs:		
E	Max E	Max E
L	(0)	(0)
F	nonzero	nonzero

F = system-dependent, possibly diagnostic, information.

TABLE E.2
EXTENDED SINGLE PRECISION FORMATS

	Single-Extended
Fields and widths in bits:	
S = Sign	1
E = Exponent	11
L = Leading bit	1
F = Fraction ≥	31
Total Width ≥	44
Sign:	+/-represented by 0/1 respectively
Unbiased exonent:	(may be stored with a bias)
Max E >	1024
Min E <	-1023
Numbers:	
Range of E	(Min E + 1) to (Max E -1)
Represented number	$(-1)^{S*}2^{E*}(L.F)$
Bottom of the exponent range:	
E	Min E
R	0 or 1
Represented number	$(-1)^{S*}2^{E*}(L.F))$
Signed zeros:	use special indicator bits, or else
E	Min E
L.F	0.0
Reserved operands:	
Signed ∞S:	use special indicator bits, or else
E	Max E
L	0 or 1
F	0
NaNs:	use special indicator bits, or else
E	Max E
L	0 or 1
F	nonzero

F = system dependent, possibly diagnostic, information

E2.3 Relationships to DIO1-DIO8 Signal Lines

Transmission of floating-point representations, via IEEE Standard 488 shall be structured in accordance with the following relationships between DIO signal lines and the floating-point numbers. In this clause MSB and LSB refer to most/least significant bit.

E.2.3.1 Single Precision

```
8      1  8      1  8      1  8      1   <-  DIO
********  ********  ********  ********
*S* E  *  *E* F  *  *  F   *  *   F  *
********  ********  ********  ********
                ^                    ^
               MSB                  LSB
```

E.2.3.2 Single Extended Precision

```
8     1  8     1  8     1  8     1  8     1  8     1 <-DIO
*******  *******  *******  *******  *******  *******
*S* E *  *E * F*  *  F  *  *  F  *  *  F  *  *  F  *
*******  *******  *******  *******  *******  *******
            ^                                      ^
           MSB                                    LSB
```

E.2.3.3 Double Precision

```
8    1  8    1  8   1  8   1  8   1  8   1  8   1  8   1 <-DIO
******  ******  *****  *****  *****  *****  *****  *****
*S*E *  *E* F*  * F *  * F *  * F *  * F *  * F *  * F *
******  ******  *****  *****  *****  *****  *****  *****
          ^                                           ^
         MSB                                         LSB
```

>>>>>> ALPHABETICAL INDEX <<<<<<

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX E
DATA MANAGEMENT AND CONTROL SOFTWARE SPECIFICATION

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APPENDIX E

DRAFT DATA MANAGEMENT AND CONTROL SOFTWARE SPECIFICATIONS

1.0 SCOPE

This specification contains minimum functional requirements for the computers, control software, and data management software for the Retirement for Cause (RFC) Inspection System. The software provides: (1) process control in the automated examination of engine component parts; (2) general data acquisition and process control; and (3) data base management functions.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this specification unless restricted elsewhere in this specification.

2.1 Government Documents

2.1.1 Specifications

MIL-T-28800B	Test Equipment for Use With Electrical and Electrical and Electronic Equipment General Specification
MIL-I-45208	Inspection System Requirements
MIL-M-38784	Manuals Technical — General Style and Format Requirments
MIL-I-18303	Test Procedures, Reproduction, Acceptance and Life for Aircraft Electronic Equipment — Format

2.1.2 Standards

MIL-STD-810	Environmental Test Methods
MIL-STD-831	Test Reports Preparation
MIL-STD-109	Quality Assurance Terms and Definitions

2.1.3 Other Publications

DI M 5120	Instruction Manual Minimum Specification Requirements

2.2 Nongovernment Documents

ANSI Y32.14	1973 Graphic Symbols for Logic Diagrams
ANSI/ASTM E268-76	Standard Definition of Terms Related to Electro Magnetic Testing

EIA STD RS-310-C	Standard for Racks, Panels, and Equipment
UL 1410	Standard for Television Receivers and Video Products
IEEE STD 100	IEEE Standard Dictionary of Electrical and Electronic Terms
ANSI/IEEE STD 488	IEEE Standard Digital Interface for Programmable Instrumentation

3.0 REQUIREMENTS

3.1 Item Definition

The computers, control software, and data management software provide: process control; data acquisition, storage, and processing; and data management tasks associated with the performance of automated nondestructive evaluation (NDE) of aircraft engine components as well as the reporting of test results. The system is composed of a master parts records system, several inspection master control systems, and multiple inspection systems. The system in total provides:

(1) A control scheme for automated parts manipulation for inspection,

(2) Process control of the inspection system in performance of the examination,

(3) Automated parts identification and location,

(4) NDE data acquisition and storage,

(5) Data processing/comparison and reporting,

(6) Part status inquiry/reporting, and

(7) Storage/retrieval of historical parts data that are resident in the overhaul facility.

The master parts records system, although not part of the RFC system, is required to provide input, storage, retrieval, update, and generalized reporting capability for all information required of the data base. An inspection master control system for each inspection facility is connected to the master parts records system. The inspection master is responsible for coordination and control of all inspection activities at the facility. As such, it interfaces between the inspection systems and the master parts records sytem. It will report, on request, the status of inspection activities that it controls. The inspection system performs the actual process control, data acquisition, processing, and reporting functions. Throughout the system, common processors will be used to provide redundancy, compatibility, replacement, and flexibility so as to minimize spare parts sources and interface complications.

3.1.1 Item Diagrams

The computer systems and associated hardware will be organized as shown in Figure E-1. The arrangement is necessary in order to meet the independent layer of software for control and data management exists. Figure E-2 shows the master parts records system to which the RFC systems interface. Inputs to this system come from the inspection master system as well as authorized independent users. Figure E-3 shows the inspection master control system. It, too, provides terminal access for authorized users to request parts status at the facility. The inspection station computer system configuration is illustrated in Figure E-4. This system interfaces to the test hardware as well as the inspection master control system.

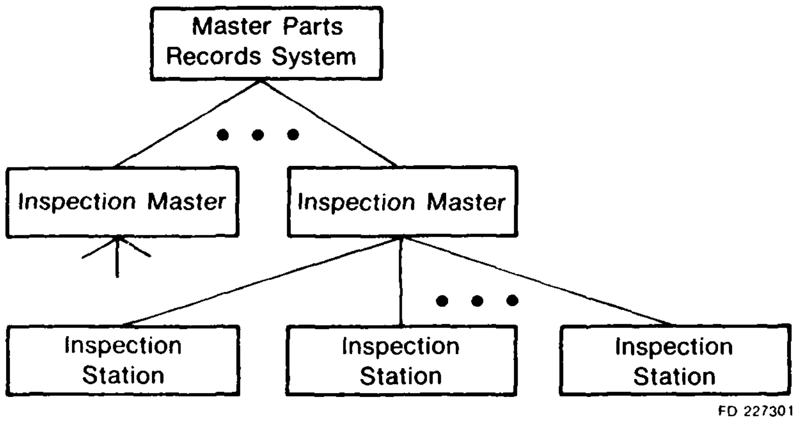

Figure E-1. RFC Computer System Configuration

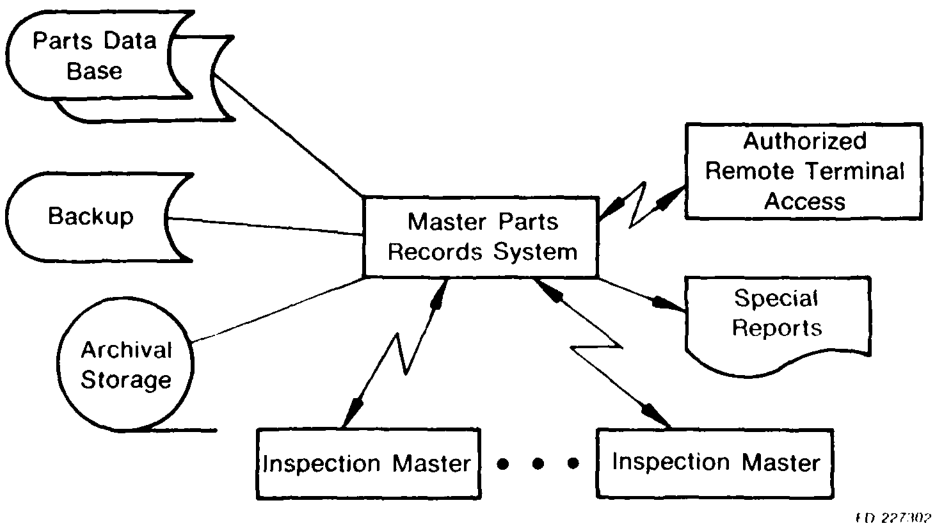

Figure E-2. Master Parts Records System

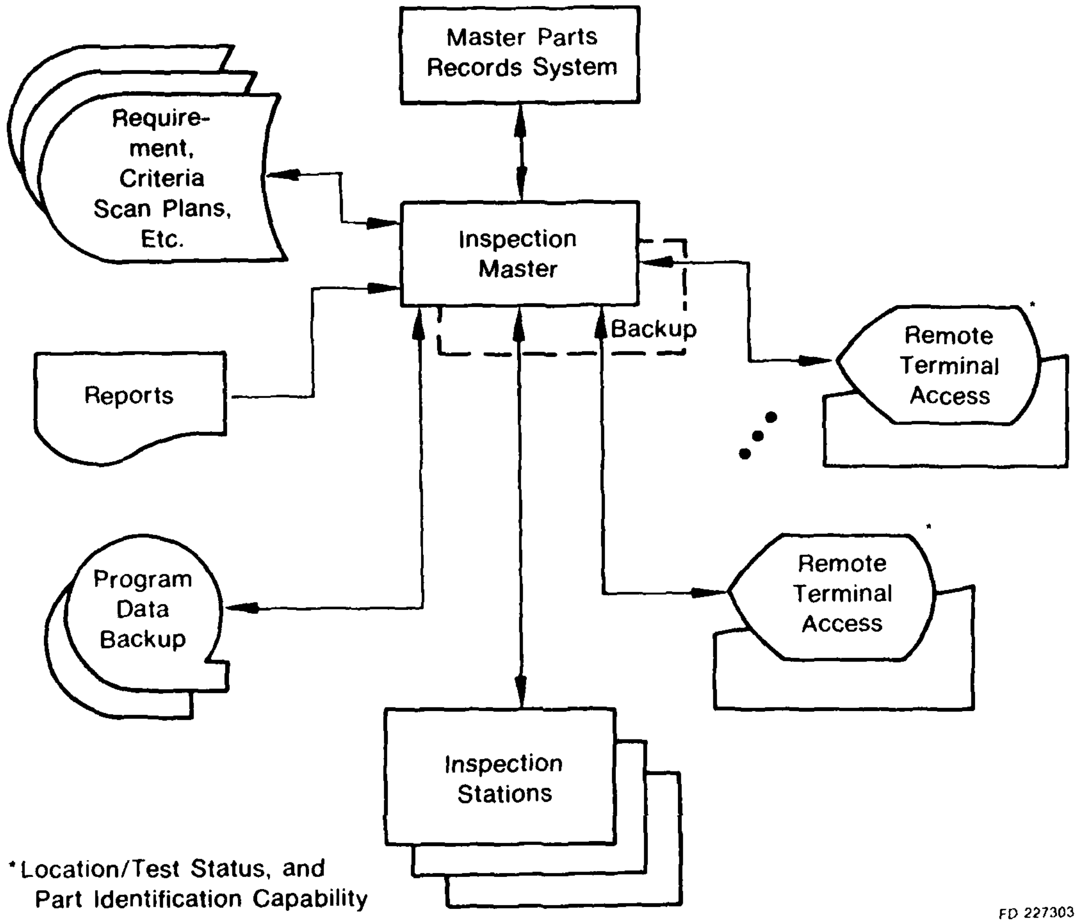

Figure E-3. Inspection Master Computer System

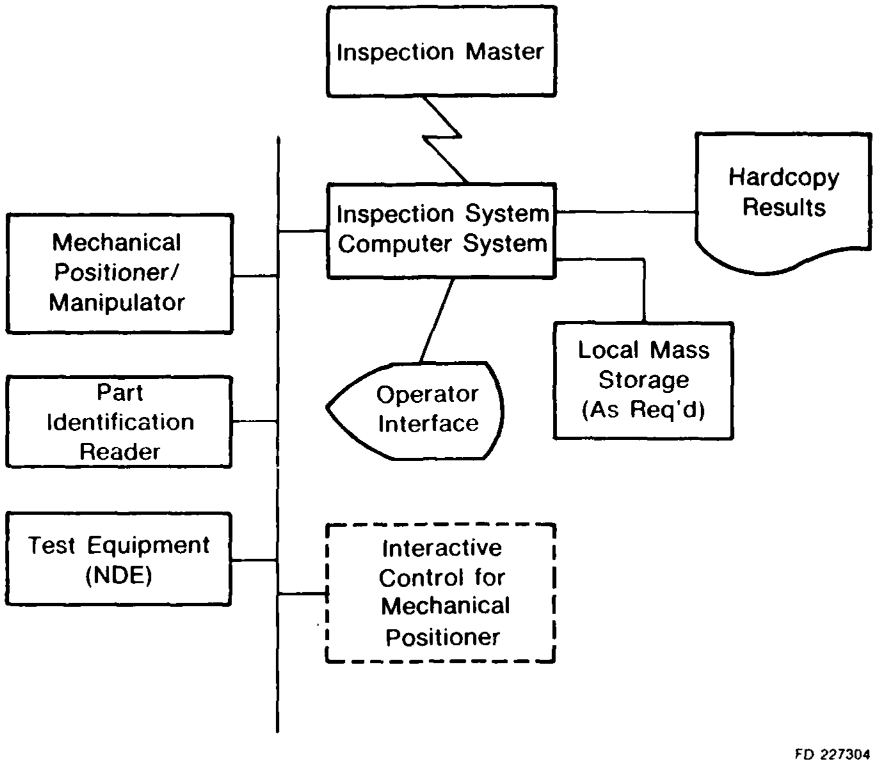

Figure E-4. Inspection Station Computer System

3.1.2 Interface Definition

3.1.2.1 Interface among the master parts records system, the inspection master system, and the inspection station computer systems will be conventional vendor-supplied equipment and software. Communications protocol will be supported in hardware to relieve processor overhead. Commonality of processors would simplify the computer-to-computer interface task and reduce software costs to ensure total system integrity.

3.1.2.2 Interface among the inspection station computer system, the NDE test equipment part identification reader, and the mechanical positioner/manipulator will conform to the IEEE 488A/1978 specification.

3.1.3 Major Component List

The Retirement for Cause Inspection System is composed of a master parts records system, an inspection master control system for each inspection facility, and multiple inspection station computer systems. These are discussed in further in Paragraph 3.4. The inspection master system interfaces to a master parts data base system which is assumed to exist.

3.1.4 Government Furnished Property List

Interface between the RFC system and existing or planned AF parts tracking or engine management systems is a necessary activity. The systems which can provide information or derive benefit are the Comprehensive Engine Management System (CEMS) and the Maintenance Job Tracking System (MJT). Specification of protocol cannot be made, as the details of either of these systems are not finalized. Neither of these systems has explicitly factored

RFC into their design. Information transfer between these systems is not considered large and may be accomplished by a variety of mechanisms. As a minimum, conventional remote job entry (RJE) protocol can be implemented in a convenient manner.

The inspection master system need not interface to existing Air Force Air Logistics Center (ALC) parts tracking/inventory systems, as these systems do not require any input other than arrival and departure from the inspection activity.

3.2 Characteristics

3.2.1 Performance

(1) Master parts data storage will allow for all data for 21 engine components for 5000 engines.

(2) Communications among computers will have protocol supported in hardware, full duplex operation, transmission speeds 56K bytes/second, and error dates less than 1 in 10^9.

(3) Communications among user consoles and computers will be R5-232-C, ANSI X 3.64-1977, full duplex, incorporate parity (single bit/byte), and operate at 9600 baud.

(4) Communications among inspection station computer systems and special purpose hardware will be IEEE 488A/1978 and operate at a minimum of 30K bytes/second.

(5) The inspection master control system must be capable of supporting inspection activities associated with 2100 parts per month inspection rate.

3.2.2 Physical Characteristics

(1) No special weight considerations are applicable to the computer equipment supplied. Conventional manufacturing concepts will apply.

(2) The inspection station computer systems will be configured in standard 19-inch rack mount cabinets, with maintenance access as provded by these cabinets from front slide mounts and rear door panels.

(3) The inspection master control system will be housed in a special room configured for it. It will have a raised computer floor and front and rear accessibility for maintenance of standard computer configurations.

(4) The master parts records system and the inspection master control system will be permanent installations with no requirements for transport or storage. The inspection station computer system racks will be mounted on casters for convenience of movement within the inspection facility. Items that are subject to damage by movement will have appropriate locking mechanisms and tiedowns.

(5) Inspection station computer systems will be built for conventional industrial use. This requires some attention to packaging details, but not extraordinary packaging restrictions.

(6) The equipment will incorporate the safety features necessary to safeguard personnel during installation, operation, maintenance, repair, and interchanging of components.

3.2.3 Reliability

To achieve reliable operation, all computer systems will have equivalent backup units, which can be readily exercised to ensure continued performance. Interchangeability with other computers in the system (resulting in graceful degradation of the whole system) is an acceptable short-term condition.

3.2.4 Maintainability

Equipment will have self-test diagnostics to ensure proper operation and assist in maintenance activities. This includes all computers, subsystems, and computer interfaces. The maximum downtime for any part of the system (assuming operation under backup) will be 1½ days. Onsite maintenance contract must be available.

3.2.5 Environmental Conditions

The environmental conditions will be restricted to temperature, humidity, and dust conditions. The master parts records system and the inspection master control system will have permanent dedicated facilities to control environmental conditions as required for proper computer operation. The inspection station computer systems will operate in a normal shop environment. Where this condition cannot be met, a small portable enclosure will be provided to maintain required operating conditions. The enclosure must provide access for maintenance and system configuration and interconnection.

3.2.6 Transportability

Computer equipment will be transportable according to conventional means currently employed by the manufacturer. Protective shipping containers and commercial carriers will be adequate.

3.3 Design and Construction

Standard manufacturing procedures will apply to the construction of the computer equipment. All interconnection cables will be connected with plug type connectors to minimize fretting and provide strain relief. Card edge connectors are not acceptable as an electrical connection unless it can be shown that the card and its interface will provide their own rigid support and locking system and will not require mechanical support for the frame, enclosure, or adjacent cards or modules.

3.3.1 Materials, Processes, and Parts

All materials, processes, and parts will be applicable to good commercial practice as required to meet the specific performance described in this document.

3.3.2 Electromagnetic Radiation

No specific requirements exist which differ from standard commercial practice.

3.3.3 Identification and Marking

No special requirements exist above those of good commercial practice.

3.3.4 Workmanship

No special requirements exist above those of good commercial practice.

3.3.5 Interchangeability

Major components of the system will be interchangeable at the board level. Interchangeability is required between all similar systems and their backup or replacement units, i.e., inspection station computer systems have interchangeable boards as do the inspection master control systems and its backup.

3.3.6 Safety

The equipment will incorporate the safety features necessary to safeguard personnel during installation, operation, maintenance, repair, and interchanging of components.

3.3.7 Human Performance/Human Engineering

No specific requirements exist that differ from standard commercial practice in computer hardware. Efforts should be made to human engineer the software, particularly on the inspection station computer system where interaction occurs with noncomputer-oriented personnel. Interaction will be clear and explicit. The initial level of self-diagnostics should be clear enough to permit operator corrective action wherever possible.

3.3.8 Standards of Manufacturer

Standards of good commercial practice will apply in the development of the computer hardware and software.

3.4 Major Component Characteristics

3.4.1 Master Parts Records System

The master parts records system provides complete data base operation for the entire system. Complete parts history is stored, retrieved, and updated on request. The system must provide storage capacity for 21 component parts of 5000 engines. This includes part nomenclature; initial inspection requirements; upgrades, changes, and exceptions to requirements; reports on physical condition of the part (dimensions); part repair history; part inspection history; and operational history as required to establish examination criteria. This system must process requests for parts history from the inspection master control systems within one day of receipt of request. It must also update the part history with relevant inspection data provided by the inspection systems. The data base system must provide generalized reporting capability to authorized users who would request special reports from the data base to confirm life cycle predictions and to analyze the volume of information available in the system to provide improved service in parts examination and reliability.

The master parts records system must provide archival storage of raw test data as required of the inspection station. It may be necessary to archive on tape the raw data acquired on examination of certain components. In this case the raw data will be passed from the bottom level up for archival storage. It must also store in some macro form the examination (scan) plans developed for the inspection of each part. It must be capable of

downloading these scan plans to the inspection station systems through the inspection master for translation into actual test control sequences. The master parts records system must contain all examination requirements for all parts in a form that is translatable into automated inspection activities. Updates to the data base in terms of test data reports, examination procedure modification or generation, and changes to examination criteria must be handled in a routine fashion.

Since the master parts records system is not provided by the RFC system, it is necessary to properly define the expected functions provided by this system for the inspection master system. Generally, the software activities are shown in block form in Figure E-5. Essentially, there are five tasks to be performed: (1) a manual records update function, (2) an inspection master monitor function, (3) a data base management function, (4) a raw data archival function, and (5) a special reports function.

The manual records update function is to enable proper handling of all inspection requirements — additions, changes, as well as deletions. This function must accommodate all manual data entries to the central data base from a variety of originating locations. The system must confirm the user's capabilities to perform requested actions by the system.

The inspection master monitor function provides the coordination of all requests and responses between the master parts records system and each inspection master system. This goes a step beyond simple bookkeeping on who requested what and ensuring he receives it — it requires anticipation of minimal reporting based on information sent. If an inspection master system requests parts history on a specific part, a report of the part's inspection status should be expected within a reasonable period of time.

The data base management function provides the obvious transaction activities of additions, updates, retrieval as well as backup and recovery functions required for proper operation and system integrity. Vendor-supplied software for the details of data base management must inherently handle the backup and recovery functions required for proper operation — this is not an applications program task. Data base recovery mechanisms must be demonstrated as an existing feature of the system.

The raw data archival function provides the capability to store specific raw data obtained from examinations of selected components. On-line retrieval of this data is not essential, rather computer access at a future date is desired. This data will be stored on tape with appropriate on-line indexing capability to assist in retrieval. This data may be compared with additional information to assess the overall performance of the RFC system. This type of feedback will permit optimization of the system over time, thereby maximizing benefits derived.

The special reports function permits authorized users to extract system data to be used as a basis for further decision making. Since the nature and content of the reports is anticipated to vary considerably, the system must provide a generalized report generator package which interfaces with the data base. Efficiency of reports generation is second to flexibility and ease of use.

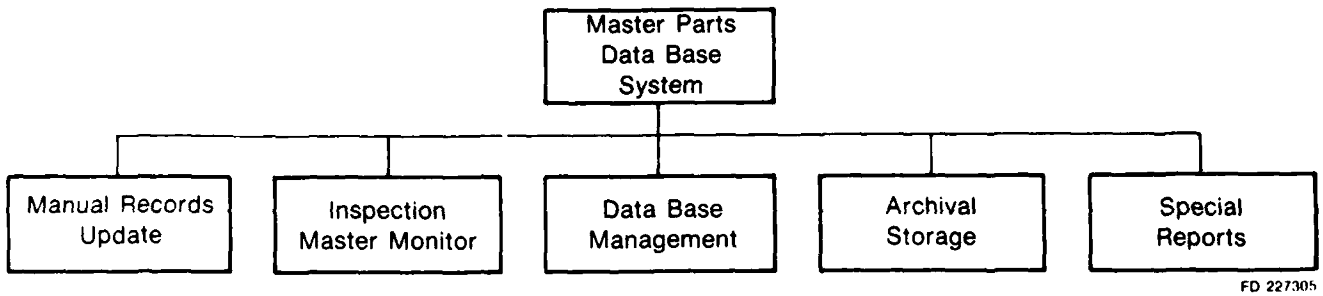

Figure E-5. Block Diagram of Master Parts Data Base Software

3.4.2 Inspection Master Control System

The inspection master control system will provide overall control and coordination of inspection activities at the inspection facility. This system will obtain parts history data required by the inspection stations, and report their results to the master parts records system. It will provide local storage of data and results for parts currently in the inspection cycle. The system will route detailed examination information to each inspection station as required. It must be capable of processing 2100 parts per month and support operation in an independent mode for a maximum of 3 days (separation from the master parts records system). In addition, it must be capable of servicing requests from authorized users pertaining to parts status, location, test results and general operational activity. Individual parts will be identified through automated part identification readers, and the identity and location of the part will be retained and updated by the inspection master control system. These readers are spread throughout the inspection facility at designated locations. Users can examine parts status through terminal requests.

Because it provides local control and coordination, the system must support some data base capability to permit orderly access and storage of data. A generalized reporting capability must exist to support special user status and data requests. The system must contain at least 1 megabyte of main memory and 384 megabytes of secondary (disk) storage. The system will have at least 2 phase encoded 9-track tape drives capable of recording at either 6250 bpi or 1600 bpi. A high-speed line printer is an essential requirement for special reports generation. The system will have complete processor, memory, and disk redundancy. Software will enable automatic operation of the backup unit on failure of the master.

The general function of the software required for the inspection master system is shown in Figure E-6. Essentially, there are six primary functions: (1) inspection station monitor, (2) master parts data base monitor, (3) location/status monitor, (4) global data storage/retrieval, (5) local data storage/retrieval, and (6) special reports.

The inspection station monitor function provides the coordination and control of activities between the inspection master and all inspection stations. This task ensures that needed information gets to its destination (both directions) as well as requiring necessary followup or reporting where required. This task should ensure the functional operability of all computers in the system (intelligible communications are both transmitted and received).

The master parts data base monitor essentially performs the same function as the inspection station monitor; however, the communications are between the inspection master and the master parts data base system. Ensuring accurate, complete, and timely communication at this level is essential to total system performance. This task must ensure that pending requests are in fact being handled and are not misplaced by either system.

The location/status monitor provides the general parts accountability function for the inspection master. This task must handle all part identification numbers not directly associated with an inspection station. The requirement is to know the location of a part as long as it is in the inspection system, as well as the inspection requirements and status of inspections on a part. This must include the associated work areas which may be involved, such as repair, dimensional checking, cleaning, finishing, etc. To accomplish this task, it is necessary to input or receive the inputs required as well as report on the status of activities that are required to be performed, knowledge of what is required, and the associated results.

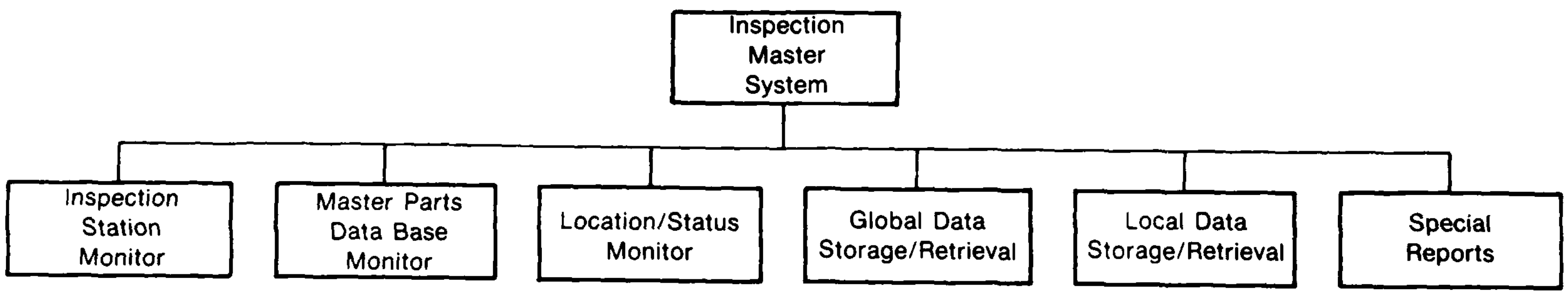

Figure E-6. Block Diagram of Inspection Master Software Functions

The global storage/retrieval function permits efficient handling of information from/to the master parts records system. The information received from the master parts records system must be efficiently used by the inspection master system. Similarly, global data acquired by the inspection master must be relayed to the master parts records system for update. As long as a part remains in the control of the inspection master, this global data must be available. On release of the part, only global update information need be relayed to the master parts records system. Essentially this consists of a summary of the results of the inspections and selected raw data (in certain cases). Occasionally, special scan plans developed for new examination techniques may be required to be transmitted to the master parts data base for subsequent retrieval and use on a general basis.

The local data storage/retrieval function permits efficient and controlled use of that data generated by the inspection master or any of of its inspection stations or related activities which are not required by the master parts records system, but are required throughout the inspection master's activities. This information would be production or performance related data which would only be of use at this level in the system to assist in maintenance management functions. Other information that is a required operational function between the inspection master and the inspection station fits this description, such as detailed diagnostics, test sequences, calibration sequences as well as operating software common to the processors. The inspection master data base software must provide backup and recovery mechanisms to protect both the global and local data bases it uses.

The special reports function permits access to the global and local data of the inspection master in a flexible and easy to use manner. This is most easily obtained through a generalized report writer interfaced to the data base software.

3.4.3 Inspection Station Computer System

The inspection station computer system will perform the actual process control, data acquisition and storage, data processing/comparison, and test reporting functions. This system will request detailed examination information on specific parts (by identification number) from the inspection master control system. On receipt of this information, it will perform the required examination by guiding the mechanical positioner/manipulator through a detailed set of motions, by controlling the settings and adjustments of the NDE test equipment, by acquiring and storing test data, and by processing the data against defined criteria (thresholds, data comparisons, etc.).

In addition, this system will provide the capability for scan plan development by permitting interactive control of the mechanical positioner/manipulator through a "follow-me" sequence controlled by the operator and monitored by the computer. The resultant scan plan will be stored for refinement into the desired test sequence. As an alternate means, the system will enable scan plan development through specification of a series of well-defined macro commands used to control the mechanical device. The inspection station computer system will also provide operator interaction throughout the automated examination sequence, and produce a hardcopy report of test results (simultaneous with transmission of these results to the inspection master control system).

The inspection station computer system is the lowest level computer in the network. It will contain 128K bytes of primary memory, 10 megabytes of secondary memory (disk) if required for the examination, and a 9-track phase encoded tape drive (1600 bpi) for storage of waveform data as required. In addition, the system will have a real-time clock; power fail/auto restart, hardware (firmware) floating point and multiply/divide, and interleaved memory, and preferably contain some features that will enhance throughput in signal processing applications. The system must be programmable in a high level language (compatible with the

inspection master control system) and contain system generation capability. It must be capable of multitasking operations to include: (1) interaction with the inspection master, (2) control of the manipulator and NDE equipment, and (3) acquisition, storage, and processing of data. Performance and interface specifications will have been previously defined.

The functional requirements of the inspection station software are shown in Figure E-7. There are six general tasks which need to be accomplished: (1) diagnostic, (2) inspection master monitor, (3) process control, (4) data acquisition/storage, (5) processing and reporting, and (6) scan plan development.

The diagnostic software is an additional feature above and beyond the stand self-test diagnostics. This software must assist in troubleshooting inspection station system problems. It is targeted for the middle ground not covered by the self-test diagnostics of each of the component parts of the system.

The inspection master monitor coordinates all activities between the inspection station and the inspection master at the inspection station level. Its purpose is to ensure accurate, complete, and timely exchange of information. It insists on followup to pending requests and, where possible, permits queueing of activities between the systems.

The process control task ensures the proper execution of inspection sequences – scan plans, instrument settings, minimum signal levels, etc. It is responsible for monitoring and adjusting test sequences (where allowed) to permit efficient and accurate inspections to occur.

The data acquisition/storage task is responsible for obtaining and storing test data in a highly efficient manner to permit maximum system throughput. This requires proper balance between efficiencies in data recording versus data retrieval for processing. If reorganization of data is required, this task accomplishes that function as well in a time frame consistent with inspection requirements.

The processing and reporting function is self explanatory. In particular, appropriate algorithms are used to determine the results of an inspection. If comparison with other data are required, this task is handled. Efficiency is of extreme concern in this task since it directly imparts system throughput more than any other task. Once the processing is done, the results are reported to the inspection operator as well as to the inspection master system. Selection and reporting of appropriate raw data is done at this point. The raw data are transmitted through the inspection master to the master parts records system for archival storage.

The scan plan development task enables simplified development of inspection movements so that new or improved techniques are easily moved from the development phase to actual shop use. The intention is to permit interactive scan plan development by a skilled NDE practitioner rather than directed implementation through a computer specialist – recognizing that inspection techniques and requirements will change in time. As stated previously, the "follow-me" technique as well as development of scans through well-defined macro commands are two of the most reasonable means of meeting this need.

4.0 QUALITY ASSURANCE PROVISIONS

The responsibility for performing all specified test/verifications rests with the supplier. The customer reserves the right to witness or separately perform all tests specified or otherwise inspect any or all tests or inspections.

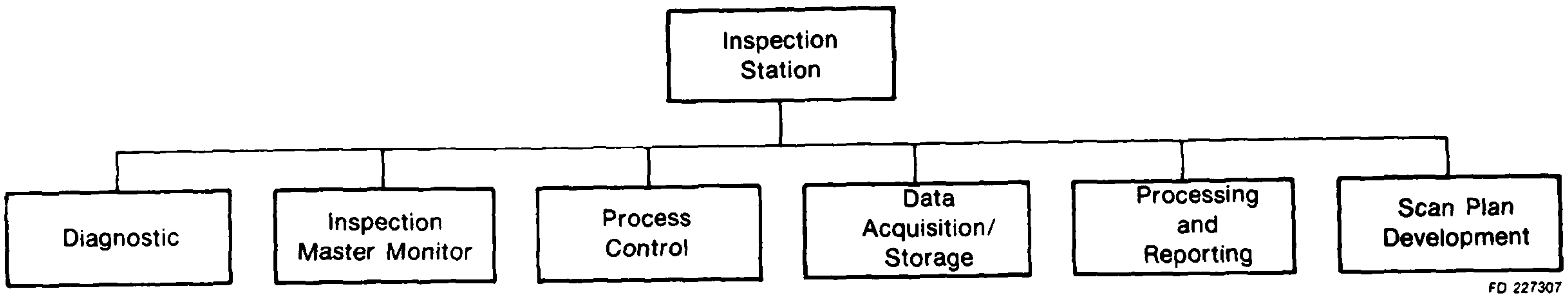

Figure E-7. Block Diagram of Inspection Station Software Functions

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX F
SCANNING EQUIPMENT SPECIFICATION

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APPENDIX F

SCANNING EQUIPMENT SPECIFICATIONS

1.0 SCOPE

This specification contains the minimum technical and performance requirements of durable scanning equipment to be used in the inspection of gas turbine engine components, including seals, disks and spacers. This scanning equipment will be part of inspection modules which will also include nondestructive evaluation (NDE) instrumentation and a control computer. Two types of modules are contemplated: eddy current and ultrasonic, each with its own set of motion requirements; therefore, two different types of scanning systems are anticipated. The equipment shall be suitable for use in United States Air Force Depot engine maintenance centers and in production shops of engine manufacturers and their suppliers. The equipment shall include mechanical equipment, motor controllers, interconnecting cables, control microprocessor, and maintenance manuals, drawings, and other necessary equipment specified within this document.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this specification unless restricted elsewhere in this specification.

2.1. Government Documents

2.1.1 Specifications

MIL-T-28800B	Test Equipment for Use with Electrical and Electronic Equipment — General Specification
MIL-I-45208	Inspection System Requirements
MIL-M-38784	Manuals Technical — General Style and Format Requirements
MIL-T-18303	Test Procedures, Reproduction, Acceptance and Life for Aircraft Electronic Equipment – Format

2.1.2 Standards

MIL-STD-810	Environmental Test Methods
MIL-STD-831	Test Reports — Preparation
MIL-STD-109	Quality Assurance Terms and Definitions

2.1.3 Other Publications

DI-M-5120	Instruction Manual Minimum Specification Requirements

2.2 Nongovernment Documents

ANSI Y32.14	1973 Graphic Symbols for Logic Diagrams
ANSI/ASTM E268-76	Standard Definition of Terms Related to Electro-Magnetic Testing
EIA STD RS-310-C	Standard for Racks, Panels, and Equipment
UL 1410	Standard for Television Receivers and Video Products
IEEE STD. 100	IEEE Standard Dictionary of Electrical and Electronic Terms
ANSI/IEEE STD. 488	IEEE Standard Digital Interface for Programmable Instrumentation

3.0 REQUIREMENTS

3.1 General Requirements

The equipment will be designed to inspect engine components using Air Force nondestructive inspection personnel at the depot level. The scanning equipment described by this specification will be capable of performing eddy current or ultrasonic inspections. The use of mechanical equipment to perform each of these different types of inspections should be assumed. Nevertheless, the scanning system controller and drive mechanism for these different scanning machines should be interchangeable. Equipment will be suitable for application in the maintenance environment with typical temperatures can be encountered ranging from 50°F to 100°F. The nominal operation temperature will be assumed to be 75°F. Equipment will be durable and packaged for easy maintenance and repair. Equipment will be designed such that it can operate with a minimum of interaction with inspection personnel and also have the capability of self-diagnosis to determine if it is operating within specifications.

The equipment will be designed and manufactured in a manner that will result in commercially reproducible equipment when procured in quantity. In addition, the equipment will be capable of precise and repeatable calibration from unit to unit and have a high degree of examination reproducibility.

Section 6.0 gives sketches with critical dimensions of components that have been selected for Retirement for Cause inspection. The inspection areas are summarized in Figure F-1 which shows sketches of typical flaw locations.

3.2 Safety

The equipment will incorporate the safety features necessary to safeguard personnel during installation, operation, maintenance, repair, and interchanging of components.

With the exception of radiation energy measurement, the equipment will incorporate the safety features per MIL-T-28800B, Pargraph 3.2.

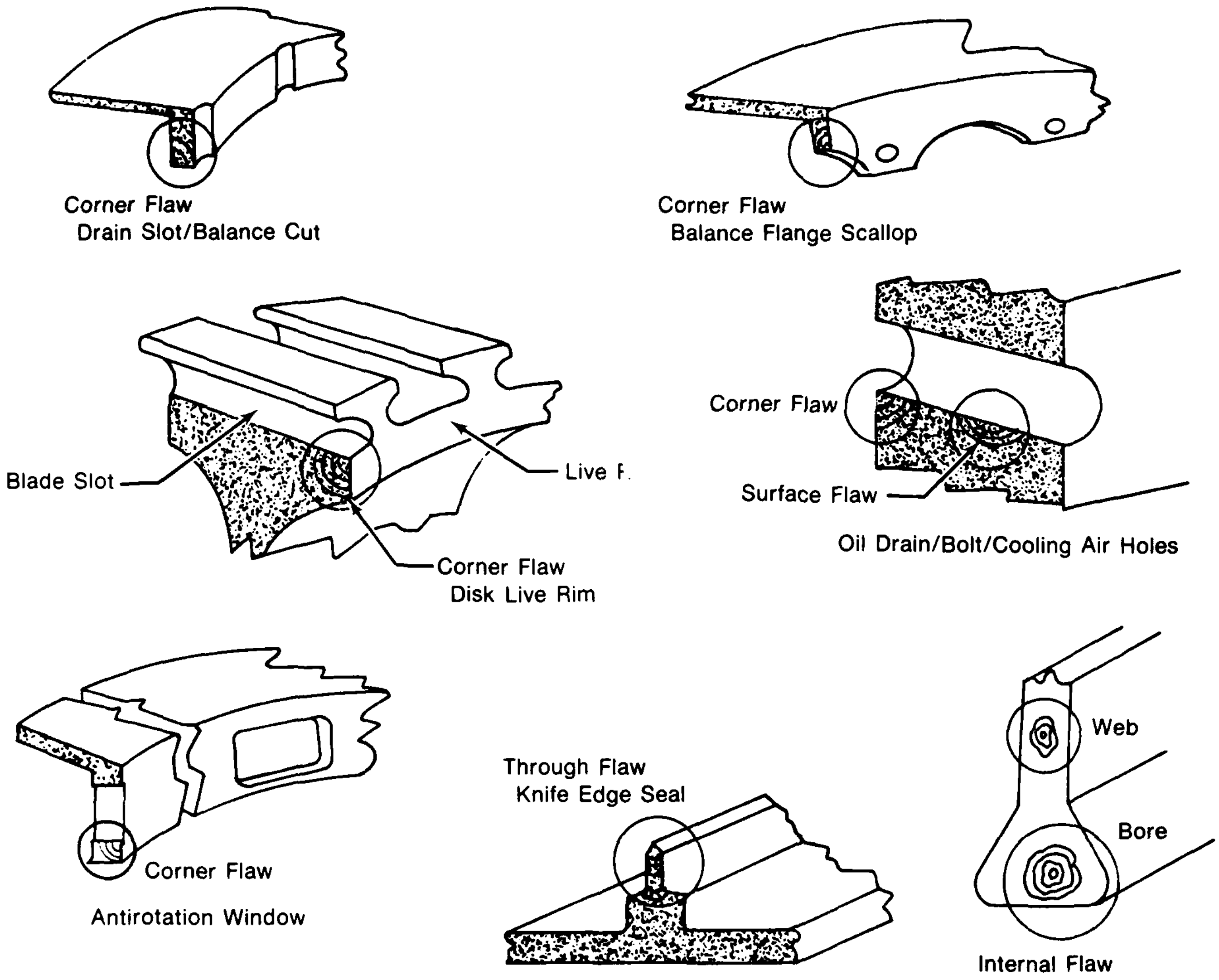


Figure F-1. Composite Sketch of Typical Flaw Locations That Must Be Inspected. Not All Features Are Found on All Parts. All Flaws Are Detected Using Eddy Current Inspection Including Internal Flaws if Near the Surface. Only Internal Flaws Are Detectable Using Ultrasonic Inspection

Protection will be provided from leakage current in excess of 1 ma peak ac and dc from any accessible conductive parts of the equipment (including control shafts with knobs removed and recessed calibration or adjustment controls) for any position of the power switch(es) in accordance with the appliance shock hazard test of UL 1410, Sections 12 and 13. All accessible electrically conductive surfaces of the equipment, when fully assembled and operating, will be at earth ground potential.

3.3 Equipment Description

The major components of the scanning equipment will consist of the following items:

(1) Mechanical scanner
(2) Motor drivers
(3) Encoders
(4) Motor controllers
(5) Scanning system control microprocessor
(6) Manual control pad
(7) Scanning tank
(8) Interconnecting cables
(9) Instruction and maintenance manuals.

3.4 Detailed Equipment Specifications

3.4.1 Equipment General Description

The functional block diagram of the mecahnical scanning equipment is shown in Figure F-2. It is intended that the only difference between the eddy current and ultrasonic system will be in the mechanical motions. All control equipment, microprocessors, stepper motors, and encoders will be of such a type that they can be used interchangeably to the greatest extent possible among ultrasonic and eddy current scanning equipment. Specifically, equipment will be constructed in a manner that facilitates maintenance and permits interchangeability of components while affording a potential means of replacing modules, cards, or subcomponents used with new state-of-the-art equipment. All electronic connectors will be either of the BNC type or strip connectors to the extent that they are compatible with environmental requirements.

Figure F-2 shows the major elements of the scanning system. The major elements shown are:

Mechanics	Implement motions which actually articulate and move inspection probes
Encoders	Indicate the position of mechanical motions
Motors	Direct motion prime movers
Motor driver/controllers	Drive motions between locations determined by scanning system controller
Microprocessor controller	Directs and coordinates system motion from stored information or external command
Manual control pad	Directs on-demand movement of any scanning system motion.

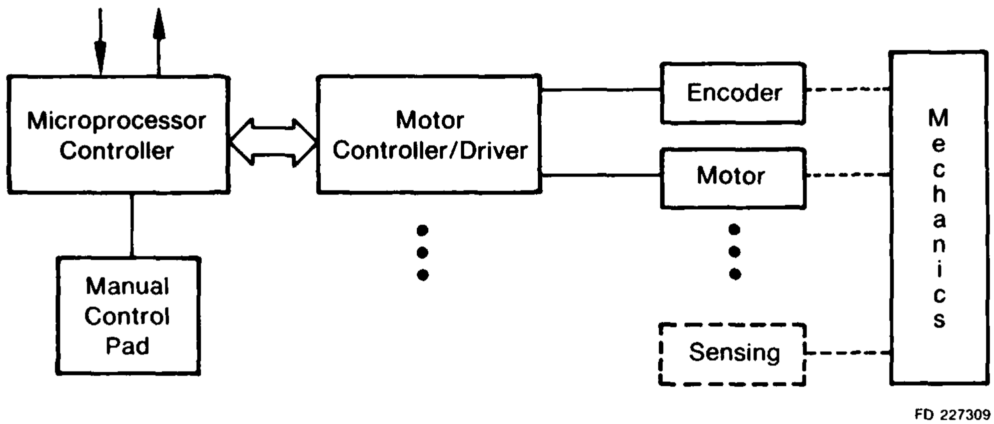


Figure F-2. Scanning System Schematic Diagram. The Control System Elements Are Interchangeable Between Ultrasonic and Eddy Current Inspection Modules

The scanning system implements motions which are elements of prepared scan sequences stored in the controller memory or on-direct command from the inspection module computer. It is anticipated that actual scanning will require a combination of these two approaches because it is not possible to anticipate fixturing errors and natural part tolerance variation in a prepared scan sequence. An adaptive control feature in the module computer will use externally supplied information to give direct commands for fine tuning movements so that the required probe-inspection surface distances can be maintained. The probe-surface spacing information will be available from the inspection module instrumentation.

The inspection module will be a highly automated system and will be operated by low-skill operators. Therefore, the scanning system must have a self-diagnostic capability to indicate to signal operators and, more importantly, the supervising computers when the equipment is malfunctioning. In addition, automatic means of reading serial numbers and reference points must be included in the mechanical system because inspection data must be recorded by specific part location and serial number.

Typically, the areas of interest on the disks and seals cannot be inspected if access is provided from only one side. For this reason, provision for two-sided access must be made.

Both eddy current and ultrasonic inspection probes are small, light, and fragile and must be electrically connected to instrumentation through the scanning system. Inspection probes, especially eddy current probes, are highly specific to the geometry of the inspection area, e.g., eddy current hole probes have diameters 0.005 to 0.1 inch smaller than the hole they inspect. Consequently, several probes are required to inspect any part. Provision must be made to change probes or scanning heads. It may be advantageous for some scanning heads to have moving elements in addition to probes to implement some of the scanning requirements. The manner in which the electrical connection is made between the probe and the scanning system is of concern since a poor connection can degrade inspection signals.

3.4.1.1 Internal Diagnostics

An internal diagnostic capability will be provided to assess the equipment and determine if it is performing as specified and designed. This diagnostic capability must be able to isolate a problem to a level consistent with a simple substitution maintenance strategy. The internal

diagnostic capability will be activated by external control or on power up and will assess the operation of at least 80 percent of the electronic components in an active state. A system will also be established to evaluate the performance of mechanical motions.

3.4.1.2 Minimum Accuracy

The accuracy with which the position of individual motions is known will be at least ±0.001 inch per foot for linear motions and ±0.1 deg for rotations. Some motions may require greater accuracy and control precision in order to meet other specified minimum capabilities.

3.4.1.3 Minimum Step Size

The maximum step size for incrementally driven motions shall be 0.001 inch for linear motions and 0.1 deg for rotations.

3.4.1.4 Automatic Tool Change

It is anticipated that not all required inspections can be accomplished using the same inspection probe. A means will be provided to automatically, on internal or manual command, change the inspection head. This change will be accomplished in less than 15 seconds in a manner that maintains the electrical and mechanical coordination between the probe and the rest of the scanning system. Provision will be made to interchange a minimum of 20 different probes.

3.4.1.5 Two-Side Inspection

It will be required that both sides of components be inspected. A mechanism for turning parts over will be provided if the scanning system configuration only permits inspection of one side of a component at a time.

3.4.1.6 Part Identification and Position Reference

A means will be provided to automatically determining the serial number and part number of components. This system will also have the capability of providing to the inspection system the reference information needed to locate and position inspection probes on components consistent with minimum capabilities.

3.4.2 Mechanical Scanners

The following sections specify the minimum capabilities required for mechanical scanners. The requirements for ultrasonic and eddy current scanning are given separately since each inspection does not require the same motions or precision.

3.4.2.1 Ultrasonic Scanner

Ultrasonic scanning will be done with the component and the inspection probe under water. The inspection probe will be maintained at a fixed distance (standoff) from the inspection surface, which ranges from 2 to 4 inches, and with its axis perpendicular or at a fixed angle to the inspection surface. The inspection will be accomplished by rotating the component about its axis beneath the inspection probe. The track of the impingent spot of the inspection beam will be a scan line that is circular and concentric with the axis of the

component. The surface zones of components over which ultrasonic inspection will be required, webs and bores, are enclosed by annuli or cylindrically symmetric sections of circles, cylinders and cones. These are shown schematically in Figures F-3A and F-3B with estimated times to accomplish them. The mechanical system must articulate the probe such that it can be made to impinge on these surfaces.

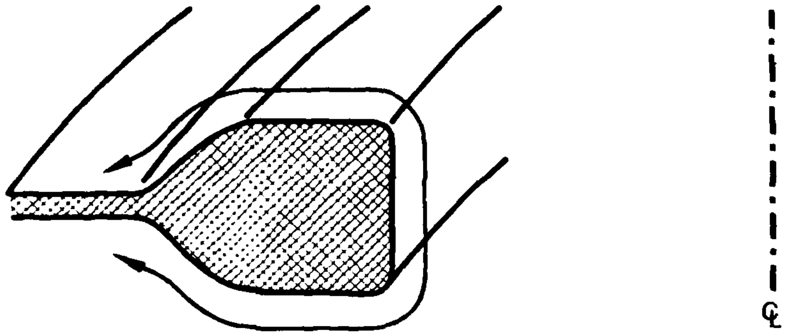
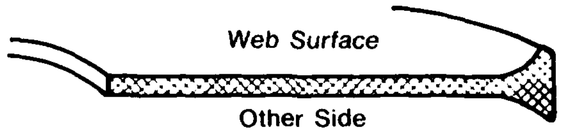


Figure F-3A. Scanning Procedures and Time for Disk Bore



Web:

Two Different Inspections Must Be Performed On Each Side of Disk.

1. Scan the Surface By Rotating the Disk Under a Noncontacting Probe Under Water

   Time: 4½ min per Side

   Calibration Time: 2 min

2. Scan the Surface By Rotating the Disk Under Contacting Eddy Current Probe

   Time: 4½ min per Side

   Calibration Time: 15 sec

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Figure F-3B. Scanning Procedures and Time for Web

Materials. The materials used to fabricate those portions of the mechanical system that potentially will be used under water shall be made of noncorroding materials that have compatible galvanic potential.

Minimum Capabilities. The minimum mechanical capabilities have been summarized in Figure F-4 as a schematic system with a specific set of motions; other combinations may also be used to meet these capabilities.

(1) The inspection probe shall be capable of being positioned on inspection zones, which range in diameter from 4 to 25 in.

(2) The inspection probe shall be capable of being positioned on the inside or outside of inspection zones that are sections of cylinders up to 6 in. in length.

(3) The inspection probe shall be capable of pointing in any direction that is between 0 deg and 135 deg from any line parallel to the component axis and emanating from one side of the component (see Figure F-4). This capability will be such that it is possible to maintain the impingement point of the inspection beam fixed on the component to within 0.01 in. when the pointing direction is changed.

(4) The direction of the inspection beam shall be controllable to ± 0.1 deg.

(5) It shall be possible to maintain the scan track to within 0.01 in. of its intended path.

(6) Standoff distance between the component and transducer shall be controllable to ± 0.01 in.

(7) The speed of component turntable shall be selectable such that the scan rate can be maintained near constant independent of radius in any inspection zone. Scan rates of 8 in. per second shall be possible.

(8) The inspection probe manipulation apparatus shall be retractable from the inspection area to permit placement and removal of the component.

(9) A provision shall be made to manually adjust the pointing direction of the inspection probe over a 5 deg cone. This is necessary because the beam emitting from an inspection probe is not always parallel to the axis of the probe casing.

(10) The settling time after changing speed or stopping motion shall be less than 50 milliseconds.

Scanning Tank. The scanning tank at a minimum shall be 40 inches in width and length. The depth will be such that any component 6 inches in length (thickness) will be no closer than 6 inches to any tank surface or the surface of the water.

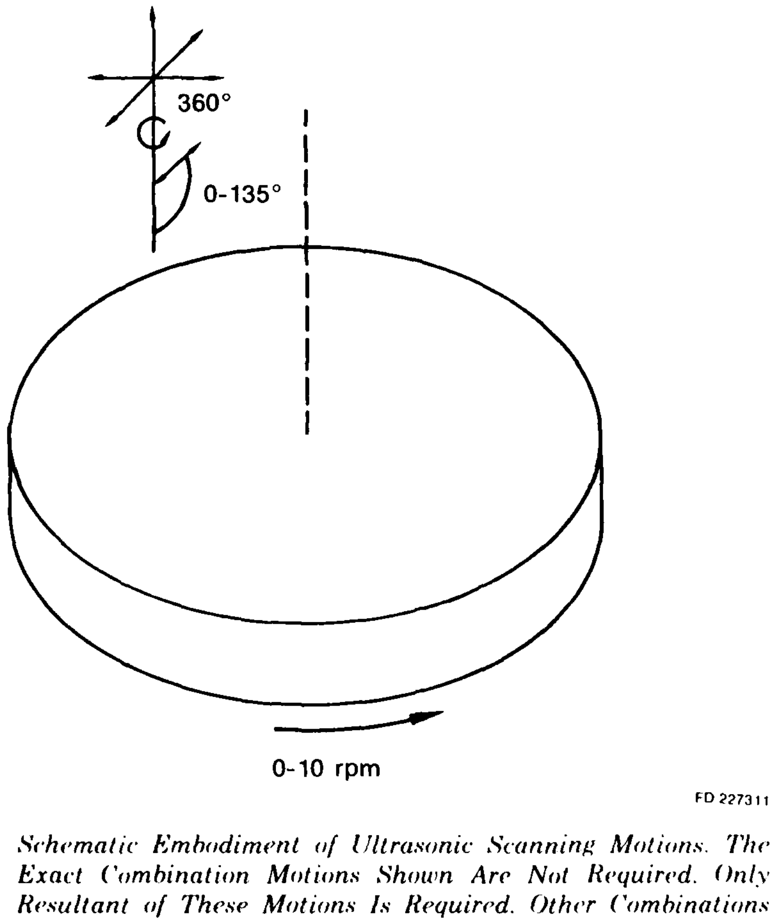


Figure F-4. Schematic Embodiment of Ultrasonic Scanning Motions. The Exact Combination Motions Shown Are Not Required. Only Resultant of These Motions Is Required. Other Combinations May Be Appropriate

At least one window will be installed in the side of the tank large enough to permit a straight-on view of the inspection probe when any component is being inspected.

The tank will be made of corrosion proof materials or be coated with a chip-resistant material that will prohibit corrosion.

The requirements for ultrasonic scanning equipment are summarized in Table F-1.

TABLE F-1. SUMMARY OF AND CAPABILITY REQUIREMENTS FOR ULTRASONIC SCANNER

Inspection Zone Diameter	4 to 25 in.
Inspection Zone Length	6 in.
Angular Range of Pointing	± 135 deg
Pointing Resolution	± 0.1
Impingement Point Positioning	± 0.01 in.
Scan Track Positioning	± 0.01 in.
Standoff Distance	± 0.01 in.
Turntable Speed	0 to 8 in. per sec scan rate
Probe Pointing Adjustment	5 deg cone
Settling Time	50 millisec
Scanning Tank Min	40 in. × 40 in. × 18 in.

3.4.2.2 Eddy Current Scanning

For eddy current inspection, the inspection probe will be in contact or near contact with the surface being inspected. There are six kinds of geometric features to be scanned. These are the web and bore surface scallops, knife edge seal, oil drain slot, rim slot corner, rotation slots and bolt holes. (See Figures F-5A through F-5F for estimated inspection and calibration times.) All features of interest can be classified into classes listed below and as shown in Figure F-6.

(1) Surfaces that are annuli or sections of cones or circles that are concentric with the component axis of symmetry. The inner and outer diameter of these zones ranges from 4 to 25 inches. These surfaces shall be scanned by rotating disks under probes that are normal to the surface being inspected.

(2) Through holes ranging in size from 0.1 inch to 1 inch in diameter and up to 2 inches long that are oriented perpendicular, parallel and at angles to the symmetry axis of the component. These holes will be inspected by inserting a rotary probe that scans the surface in a helical trace as it enters the hole.

(3) Curvilinear edges that approximate a sector of an ellipse. These will be inspected by simultaneously rotating and translating the inspection probe and/or component.

(4) Complex surfaces that are approximately sectors from an elliptical-shaped hole up to six inches long. These will be inspected by successively inserting the probe. The probe will be rotated a small amount between each insertion.

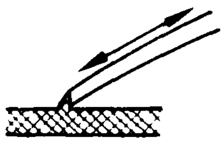
Scallop:

Scan Along the Edge of a Complex Curve with a Contacting Probe, Then Rotate to Next Location

Time: 10 sec

Calibration Time: 20 sec

Figure F-5A. Scanning Procedures and Time for Scallops



Knife Edge Seal:

Scan Along the Edge by Rotating Seal Under a Contacting Probe

Time: 1 min

Calibration Time: 20 sec

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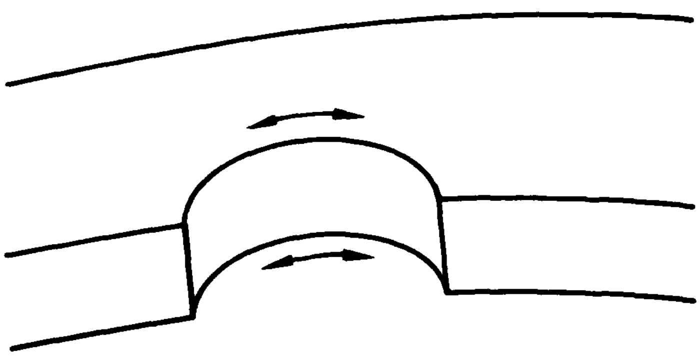
Figure F-5B. Scanning Procedures and Time for Knife-Edge Seals



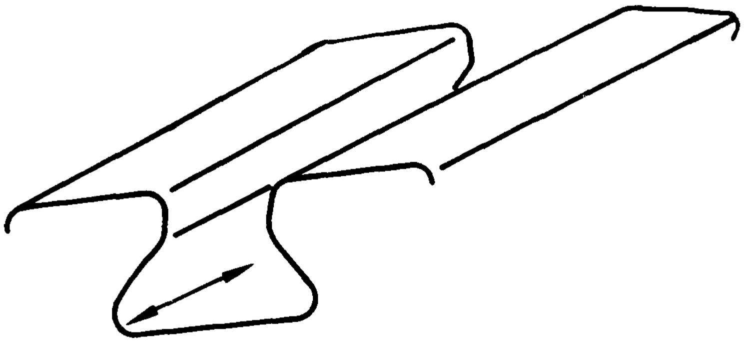
Oil Drain Slot:

Scan Along the Edge of a Simple Curve, and Then Rotate to Next Location

Time: 10 sec

Calibration Time: 20 sec

Figure F-5C. Scanning Procedures and Time for Oil Drain Slots



Rim-Slot Corner:

Insert and Withdraw a Contacting Probe, Then Index to a New Location

Time: 10 sec

Calibration Time: 20 sec

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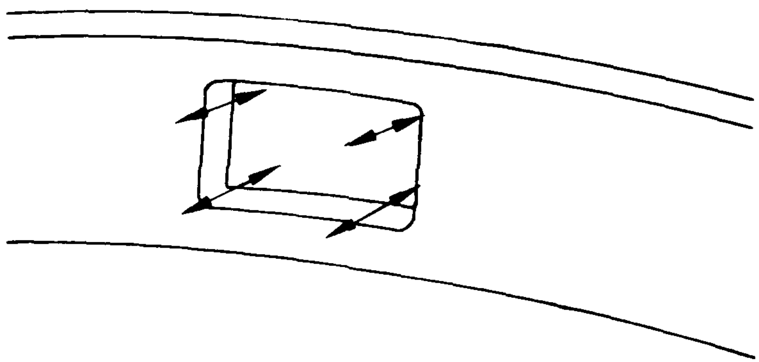
Figure F-5D. Scanning Procedures and Time for Rim Slots



Antirotation Window:

Scan In and Out Along Each of the Four Corners with a Contacting Probe

Time: 10 sec

Calibration Time: 20 sec

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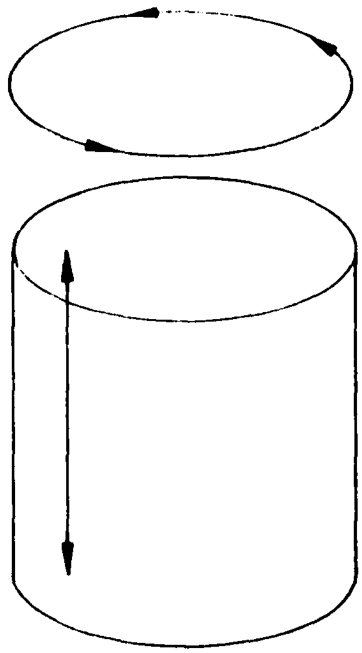
Figure F-5E. Scanning Procedures and Time for Antirotation Windows



Holes:

Insert and Withdraw a Rotating Noncontacting Probe, Then Index to the Next Location. The Nominal Probe/Surface Clearance Is 0.005 in.

Time: 15 sec

Calibration Time: 30 sec

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Figure F-5F. Scanning Procedures and Time for Boltholes

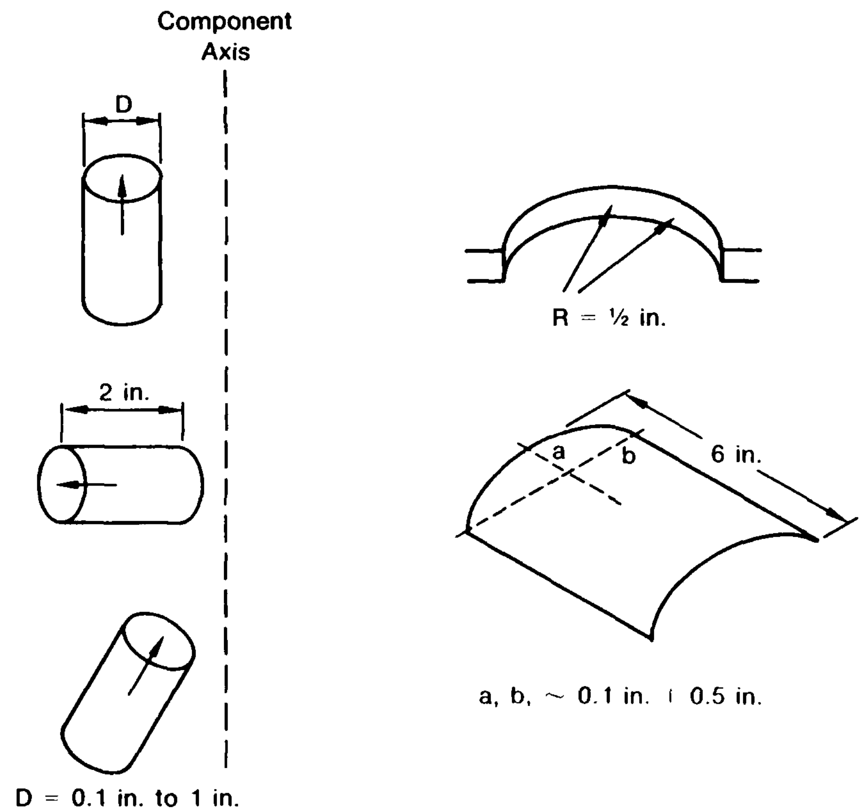

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Figure F-6. Schematic of Surfaces Which Require Eddy Current Inspection. Arrows Indicate Side of Surface of Interest. All Ultrasonic Entry Surfaces Also Require Eddy Current Scanning

Holes, curvilinear edges, and complex surfaces are repetitive features on components. The component must be rotated (indexed) after each feature is inspected to bring the next one into position.

Minimum Capabilities. The minimum mechanical capabilities have been summarized in Figure F-7 as a schematic system with a specific set of motions; other combinations of motions may also be used to meet these capabilities:

(1) The inspection probe will be capable of being positioned on inspection zones which range in diameter from 4 to 25 inches.

(2) The inspection probe will be capable of being positioned on the inside and outside of zones that are sections of cylinders up to 6 in. in length.

(3) The equipment will be capable of maintaining a scan line separation to within 0.01 in. of its intended path.

(4) Standoff distance between the inspection probe and the inspection surface will be controllable to ± 0.001 in.

(5) The inspection probe will be pointable in any direction between 0 and 90 deg from the component axis or a line parallel to it as shown in Figure F-7. This may be accomplished by tilting the component.

(6) The pointing direction of the probe will be controllable to within +0.1 deg.

(7) The probe assembly will have an axial movement capability of 6 inches. This capability will facilitate inspection of holes.

(8) The angular position resolution of component rotation will be ± 1 minute of arc.

(9) The speed of component turntable will be selectable such that the scan rate can be maintained constant to within 2 percent independent of radius in any inspection zone. Scan rates of 8 in. per second will be possible.

(10) The inspection probe manipulator will be retractable to permit placement and removal of the component.

(11) The settling time often changing speed or stopping motion will be less than 50 milliseconds.

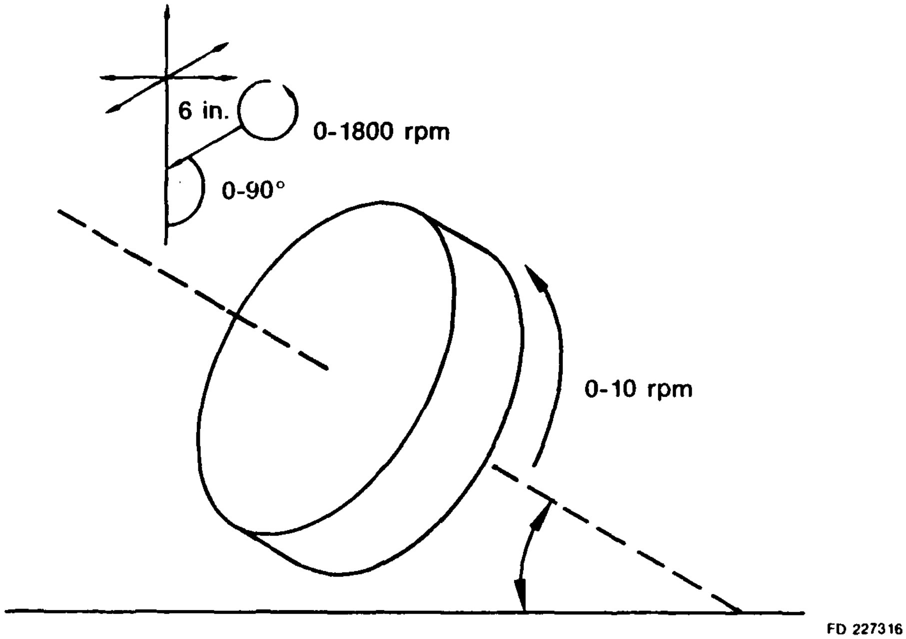


Figure F-7. Schematic Embodiment of Eddy Current Scanning Motions. The Exact Combinations Shown Are Not Required. Only Their Resultant Is Required. Other Combinations May Be Appropriate in Meeting Specifications. All Motions Are Not Necessary To Inspect All Locations and Therefore Need Not Be Available at All Times

The capability requirements for the eddy current scanner are summarized in Table F-2.

TABLE F-2. SUMMARY OF AND CAPABILITY REQUIREMENTS FOR EDDY CURRENT SCANNER

Zone Diameter	4 to 25 in.
Zone Length	6 in.
Scan Line Positioning	± 0.01 in.
Standoff Distance	± 0.001 in.
Range of Angular Pointing	± 90 deg
Pointing Resolution	± 0.1 deg
Probe Axial Range	6 in.
Turntable Position Resolution	± 1 minute of arc
Turntable Speed	0 to 8 in. per sec scan rate
Turntable Speed Control	± 2%
Settling Time	50 millisec

3.4.2.3 Fixturing

The mechanical scanning equipment will be fitted with a universal fixture that is capable of holding and centering component to an accuracy of ±0.01 in.; cylindrical surfaces of the component are to be used for holding. These surfaces may have their inside or outside surfaces. This fixture will be universal in that it can be used to hold any one of a predetermined group of components. This fixture will be capable of being actuated from either a manual or computer command.

3.4.3 Motor Controllers/Drives

Motor controllers will be of the preset indexer type. They will interface with computer equipment using IEEE 488A/1978 protocols. Motor controllers will be capable of providing current position information to the control processor in addition to signaling motion completion. They will have a self-diagnostic capability that can indicate controller operational capability to the external controllers. Sufficient nonvolatile internal memory will be provided to log hardware error conditions. The number of entries and contents of the hardware error log will be accessible both through a manual integration and through the system controller. In addition upon request, the instrument will provide the version/revision identification number off its internal programming, serial number, and the serial numbers of modules inserted if applicable. Motor drivers of the chopped drive type will not be used. The number of types of controller/drives will be minimized.

3.4.4 Motors

Mechanical scanner(s) will be driven by motors capable of accelerating to full speed from rest in one second. Motors used in incremental motions will be of such a size that can reach speeds of 6 inches per second for linear motions and 10 deg per second for angular motions. Motors will be sized such that the above motions can be accomplished with fixturing, plus components of up to 1150 lb and probe head assemblies up to 2 lb in place.

3.4.5 Encoders

All motions will be encoded with absolute encoders to indicate the position of the axis. The precision of encoders will be consistent with the minimum tolerance and minimum capability requirements. Placement of encoders at or as close as possible to the end of mechanical sequences is encouraged. Encoders will be durable and be capable of meeting environmental requirements. The number of types of encoders used for all equipment will be minimized.

3.4.6 Mechanical System Controller

The mechanical system controller will direct the motion of the multiaxis of the mechanical scanner. This system will manage all motion and provide position information on the location of each axis.

The mechanical system controller will be microprocessor based with a minimum of 128K byte memory. It will be assumed that mass storage and IO terminal capabilities will be provided as part of the inspection module computer. A provision will be provided to add mass storage and terminal capabilities if it is found to be appropriate at a later time.

Communication between the mechanical system controller and both the inspection module computer and motor controller/drives will be done using IEEE 488A/1978 protocol.

The mechanical system controller will direct scanning system motion on commands received from a manual control pad or the inspection module processor. It will also direct motion sequences (scan plans) that have been transmitted (down-loaded) from the inspection module computer and stored in the mechanical system controller.

A provision will be made to modify scan sequences in real time to accommodate minor tolerance variations in part geometry or in fixturing alignment. Information needed to establish variation parameters will be derived from location determinations done before scan initiation or during scanning and supplied to the scanning system controller by the inspection

module computer. This information will be derived from the sensing capabilities of inspection probes. Ultrasonic instrumentation can provide standoff distance and an indication of change in ultrasonic beam entry angle. Eddy current instrumentation can also provide standoff distance. This variation sensing information can be used to effectively meet scanning system standoff and alignment requirements. The mechanical system controller will be capable of interpreting and responding to scan plans described in terms of functional commands such as move, increment, rotate, accelerate, or the other terms which can be used to indicate motion of the scanning mechanics.

3.4.7 Manual Control Pad

A control pad will be provided to manually enable motion of all scanning axes. This pad will be of size and weight to be held in one hand. All motions will be enabled in both forward and reverse directions.

3.4.8 Enclosure

The enclosure for the mechanical system controller will be of the type that provides its own ventilation, circulation, and cooling if necessary. It will contain dust filters and be capable of maintaining the temperature needed for proper element operation in external operational environment specified previously. This enclosure will provide slides or rails such that individual modules and units can be removed for servicing or replacement. Modules will be such that they will permit equipment operation when the module is in the extended position.

3.4.9 Identification Plates

Identification plates will be mounted on each module indicating its type, serial number, and mating cable connections.

3.5 Parts, Materials, and Processes

All parts, materials, and processes will be applicable to good commercial practice as required to meet the specific performance as described in this specification. The use of radioactive materials will be limited to display devices.

3.6 Finish Color

The finishing color of equipment enclosure will be that normally supplied by the maufacturer.

3.7 Design and Construction

3.7.1 Design

Equipment will be designed with the intention of having durable, reliable, and easily maintainable equipment that can operate in the depot maintenance environment. Maximum attention must be given to maintenance and self-diagnostic capability so that it is possible to ascertain whether or not the equipment is operating without the use of highly skilled personnel.

3.7.2 Construction

Provisions will be made to ensure that the electrical connectors are mated only to the appropriate counterpart. When design considerations require close proximity of connectors of similar configuration, designs and construction will include built-in adjustments or compensating devices for restoring the equipment to specified tolerances. These devices will be capable of compensating for the change in performance that is expected to occur over a period of one year.

All modules will be connected with plug-type connectors of the type that will minimize fretting and corrosion which might lead to possible failure or create high-resistance paths. Cabling and wiring will be sheathed and guarded to minimize the effect of abrasion and wear.

Particular care should be excercised in the design and selection of cabling and connectors to assure rugged and durable performance since it is known that cabling faults are a common cause of equipment malfunction.

All analog circuitry will be constructed on printed circuit boards. Digital construction will be printed circuit boards in accordance with manufacturer's practices. All digital circuit boards must be operable with extender cables.

3.7.2.1 Test Points

Test points will be provided in the form of terminal points that are accessible of evaluation of circuits while equipment is operational and covers the removal. Test points will be identified on the layout and the circuit schematic and on the chassis or circuit board where they are located.

3.8 Marking and Identification

Identification and supplemental plates may be located on the equipment. Information plates will contain the following information: model number and revision, equipment name or description, serial number, power requirements, and manufacturer's name.

3.9 Environmental Requirements

The equipment will meet the appropriate military equipment specification. It will be operable in the maintenance environment and not require excessive tooling or dust filtration for operation. Equipment will operate under the vibration requirements typically found in the maintenance environment. It will be not so fragile as to be able to take the standard wear and tear and vibrations encountered in such an environment.

3.9.1 Electromagnetic Interference

The effects of electromagnetic interference will be minimized by appropriate grounding and isolations. The use of optical isolation is recommended. Chopped stepper motor drives and other noise and generating approaches should be avoided.

3.10 Maintainability

Maintainability will be a prime consideration during the design and manufacture of the equipment. The maintainability will be developed in such a manner that it will allow the required work to be performed by Air Force maintenance personnel. Maintenance plans based upon element substitution are acceptable.

3.10.1 Diagnosing Cause of Failures

Equipment will have the capability of self-diagnosing the cause and location of failures. This capability will identify the specific elements that must be replaced to reinstitute operation. The mean repair time will be 90 minutes. The maximum tolerable time will be 115 minutes. The maximum corrective maintenance will not exceed 270 minutes.

A maintainability program will be developed during the design phase and completed during the manufacture phase. The program will consist of a plan to demonstrate the maintainability, an explanation of how to use the maintenance manual, and all acceptable schemes that can be used to provide remedial action. In general, the first line maintenance approach will be replacement. To accomplish this, a detailed list of spare parts will be provided. The equipment self-diagnostic capability will be sophisticated enough to provide the low-level operator with the necessary information to indicate which module must be replaced to restore operation.

3.11 Interchangeability

Major components of the system supplied by manufacturers will be interchangeable over the entire life of the production cycle. Both mechanical and electrical aspects of the equipment will have this interchangeability feature.

3.12 Documentation

An instruction manual and other information required for depot use of this equipment will be provided by the contractor. A manual addressing the maintenance of this equipment, detailed operation, and necessary instructions for initial setup will be provided. Three bound copies suitable for a six-month field trial of the equipment will be provided with each set of equipment ordered. Detailed component and assembly drawing will be provided.

3.12.1 Metric-English Equivalent

All component dimensions illustrated in drawings will be provided in metric (SI) units followed by English units (for those commonly reported English units).

3.12.2 Glossary

A glossary of terms will be established by the contractor for the purpose of identifying controls, operation terms, and maintenance manual and labeling equipment. A glossary will be submitted to the purchaser for review and approval to assure that standard nomenclature is established prior to the supplier's use of these names and abbreviations.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection and Tests

Unless otherwise specified, the supplier is responsible for the performance of all inspection and test requirements specified. Except otherwise specified, the supplier may utilize his own facilities or any commercial laboratory. The Procuring Activity reserves the right to witness or perform any of the inspections set forth in this specification.

4.2 Quality Program

Contractor will provide and maintain a quality program which includes the following as a minimum:

4.2.1 Inspection System

An inspection system capable of monitoring the mechanical dimensions and the electrical performances required to manufacture the equipment will be provided.

4.2.2 Initial Quality Planning

The contractor during earliest practical phase will conduct a review of the requirements of the contract to identify and make timely provisions for special controls processes, test equipment, fixtures, tooling, and skills required for ensuring product quality. This initial planning will recognize the need to prepare and update inspection test procedures and techniques and to provide required equipment and services as well as interfacing these quality controls with manufacturing procedures. The planning will also provide appropriate review to assure applicability of manufacturing, inspection, testing and documentation.

4.2.3 Design, Drawing, and Configuration Controls

A design review meeting involving the contractor and the Procuring Activity will be held prior to fabrication of any units. Contractors will notify the procuring activity at least 30 days in advance of the time and place of design and review. Contractors will establish procedures to assure timely incorporation and control of the configuration. These procedures will include a control of document transmittals to all effective organizations to assure that work and quality functions are accomplished in accordance with the latest approved documents and that obsolete documents are removed from use. Drawing controls must verify that the last built configuration conforms to applicable specifications, drawings, and other contractual requirements including all authorized changes and modifications, and that the effective documents are revised to accurately describe the last built configuration.

4.3 Tolerances

Tolerances on as-specified performance parameters and physical dimensions will be indicated. Where no tolerances are shown, a nominal value will be applied, and the tolerance of ± 5 percent will be applicable.

4.4 Inspection and Test Requirements

Equipment will be inspected and tested as a complete article. Where detail test procedures are not specified, the contractors will develop the procedure necessary to provide objective evidence that the requirements have been met. These procedures will be included in the overall test procedure plan. Sequence of testing will be approved by the procuring activity. When modifications, repairs, or replacements are required after final testing or inspection, there will be a reinspection and a retesting of any characteristic defect.

4.4.1 Test Conditions

Unless otherwise specified, test conditions will be conducted at ambient temperature and climatic conditions existing in the test place.

4.5 Test Procedure Plan

Procedures for conducting first article tests will be prepared by the contractor and submitted to the Procuring Activity for acceptance at least 30 days prior to the scheduled date of tests. The review activity will not exceed 30 days. The Procuring Activity will reserve the right to modify the test or require additional tests if necessary.

4.6 Test Report

Test data will be recorded during testing in the form that would permit reference to the test procedures and equipment use and will provide for actual readings of measure values. These data will be submitted in a test report within 30 days upon the completion of the tests.

5.0 PREPARATION FOR DELIVERY

5.1 General

All equipment will be examined in accordance with the requirements stated and acceptance of the time. Upon acceptance of the item, it will be shipped to the procuring activity.

5.2 Packaging

Contractors will provide reservation packaging and packing which will afford adequate protection against physical damage during shipment of all deliverable items.

6.0 F100 PARTS SELECTED FOR RETIREMENT-FOR-CAUSE ANALYSIS

Figures F-8 through F-28 show the critical location and key dimension of the 21 F100 parts that have been selected to undergo Retirement for Cause structural analysis. The Retirement for Cause inspection system must have the dexterity to evaluate all these locations.

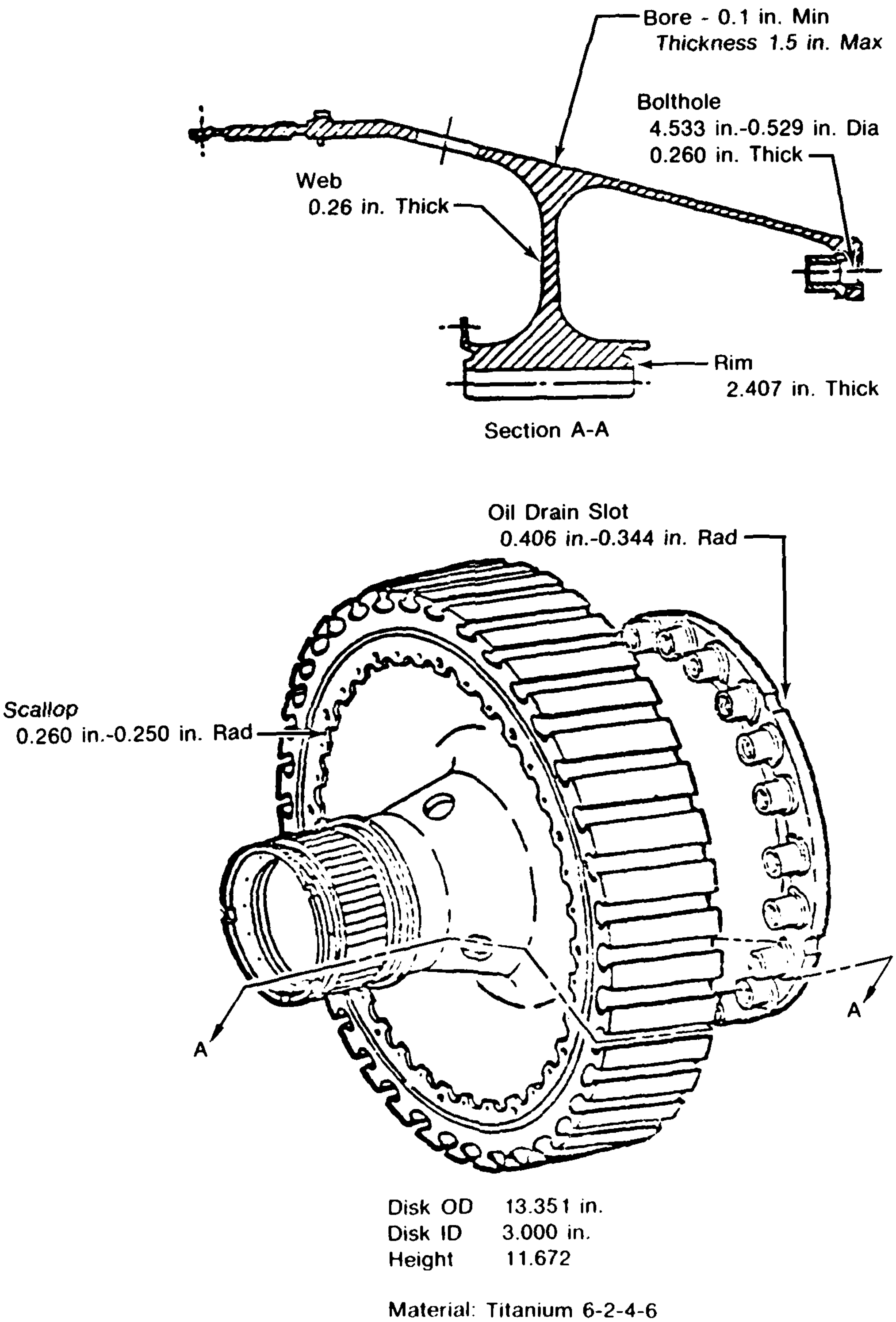


Figure F-8. 1st-Stage Fan Disk (P/N 4046741)

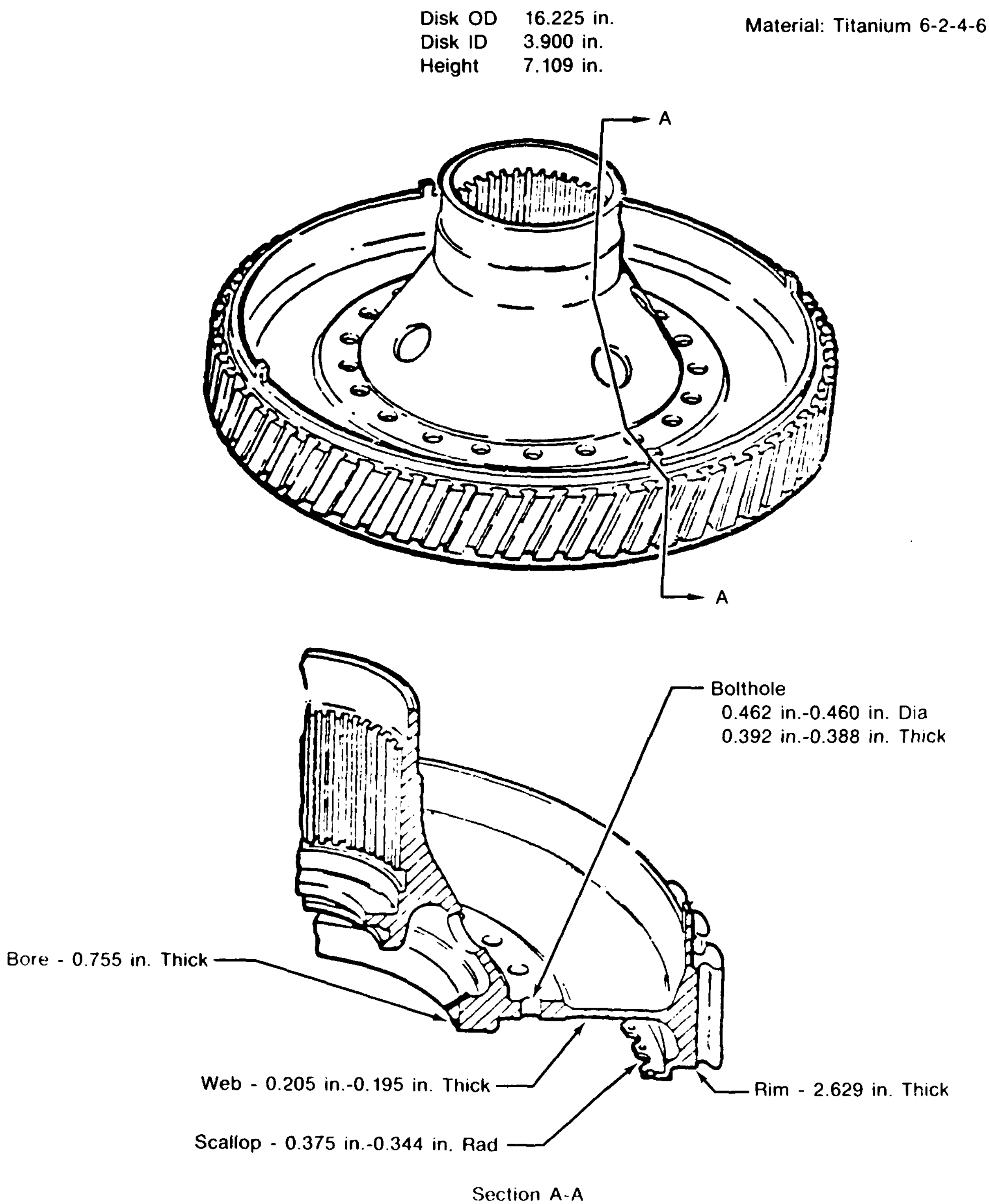
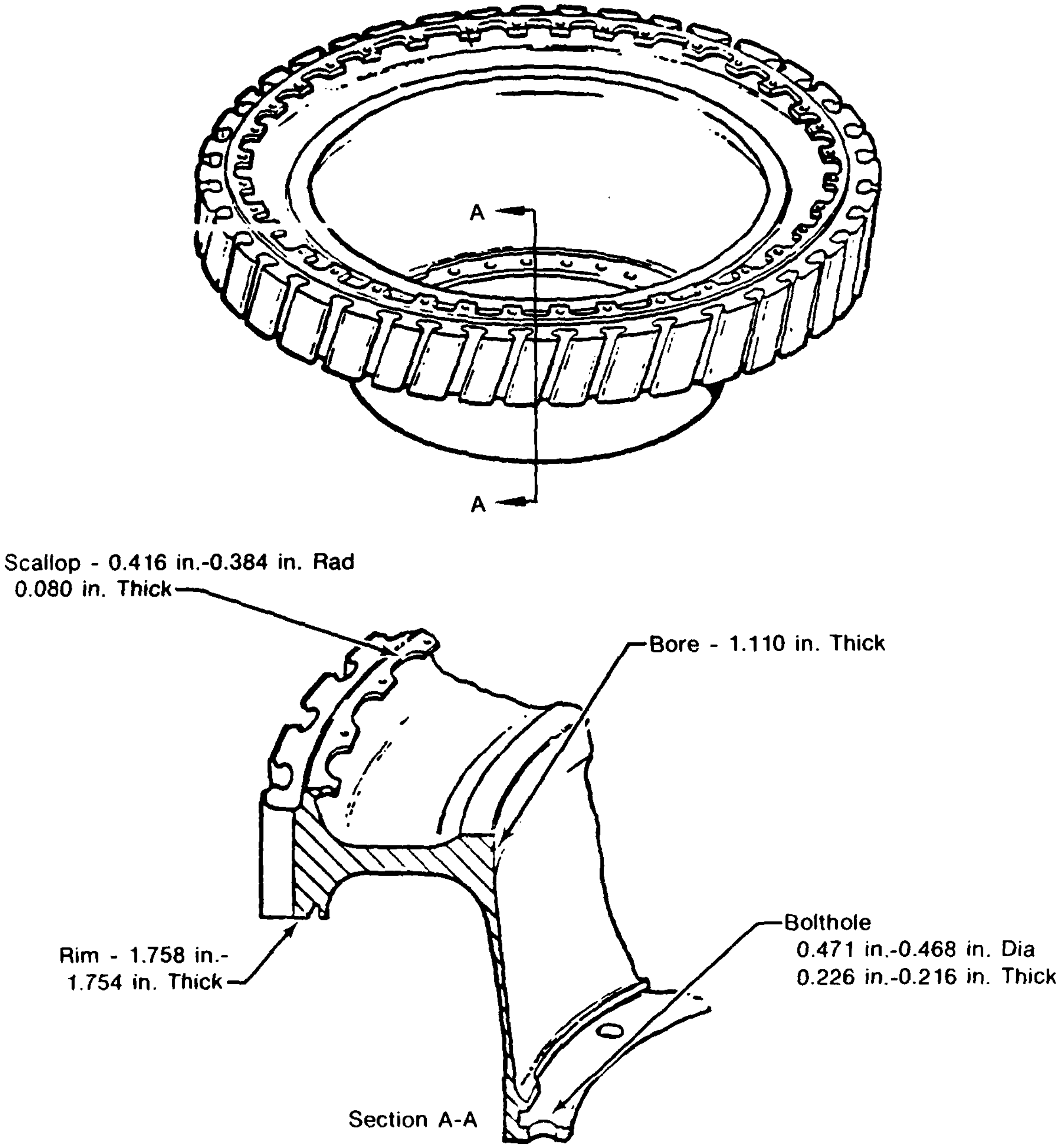
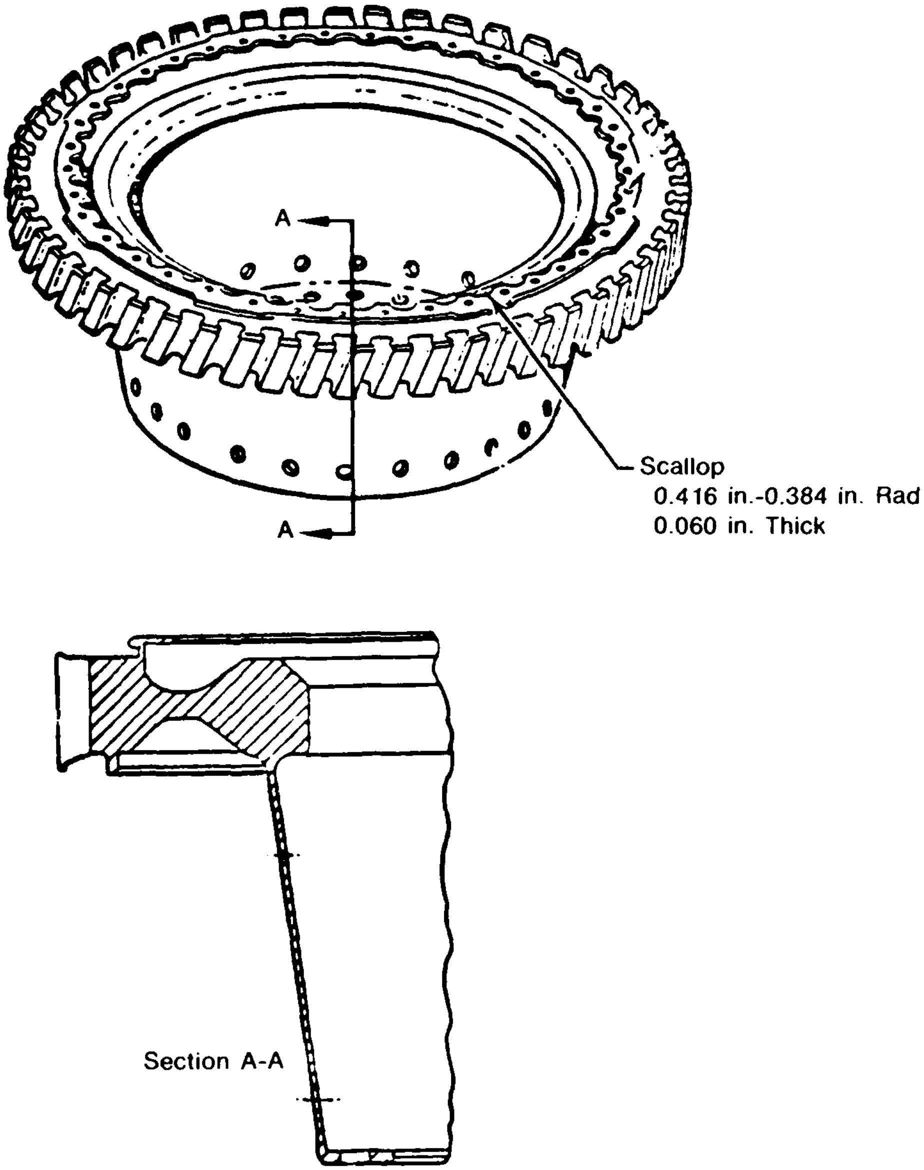


Figure F.9. 2nd-Stage Fan Disk (P/N 4018902)



Disk OD	16.865 in.	Material: Titanium 6-2-4-6
Disk ID	9.091 in.	
Height	5.8525 in.	

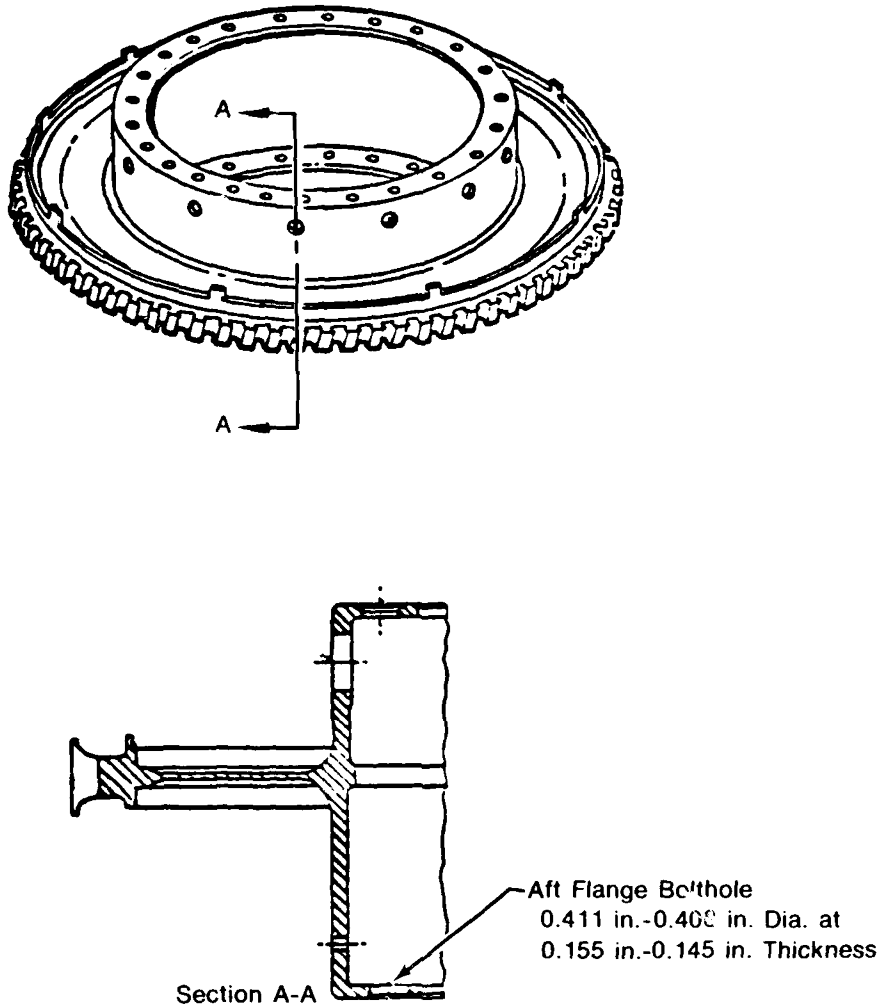
Figure F-10. 3rd-Stage Fan Disk (P/N 4048903)



Disk OD	16.865 in.	Material: Titanium 6-2-4-6
Disk ID	9.091 in.	
Height	6.220 in.	

FD 223590

Figure F-11. 4th-Stage Compressor Disk (P/N 4030604)



Disk OD	16.776 in.	Material: Waspaloy
Disk ID	*8.710 in.*	
Height	4.499 in.	

Figure F-12. 7th-Stage Compressor Disk (P/N 4011337)

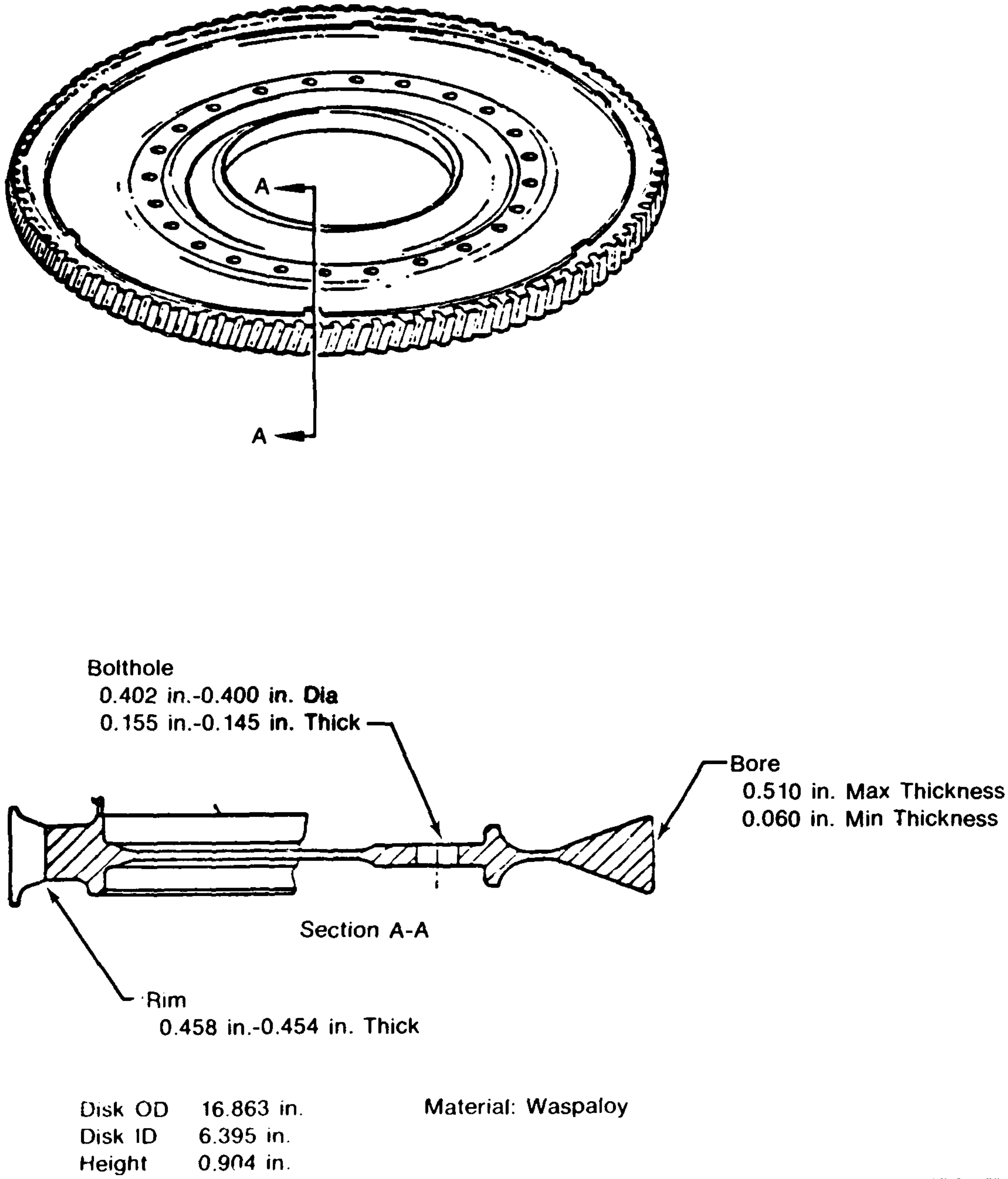


Figure F-13. 8th-Stage Compressor Disk (P/N 4040108)

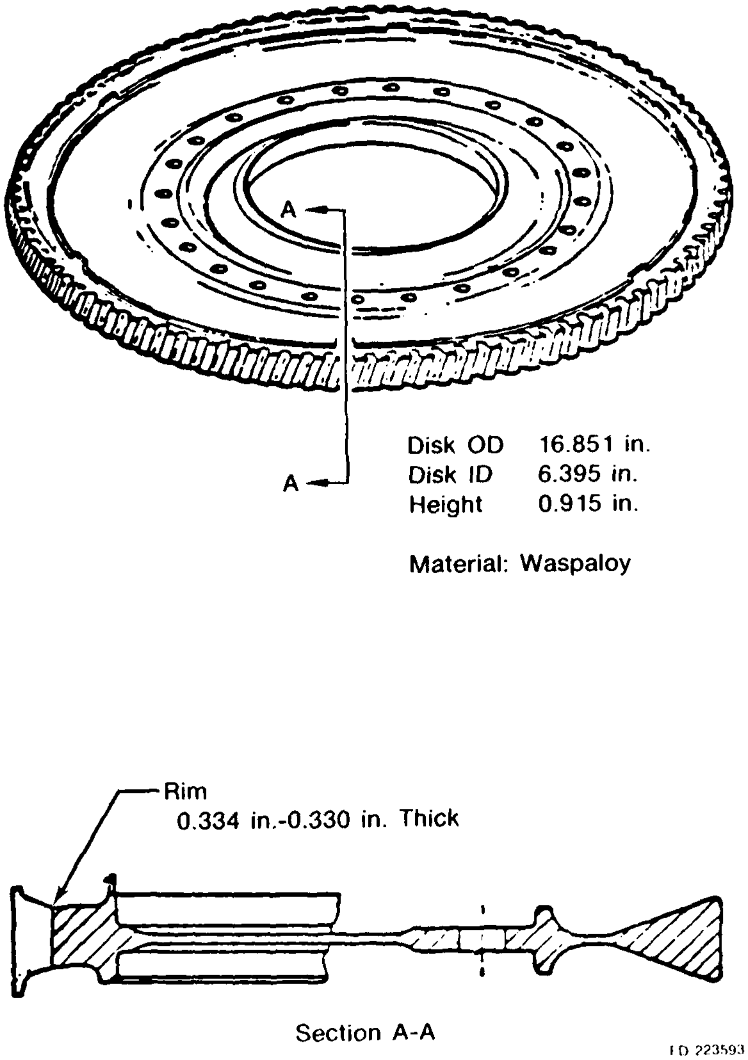
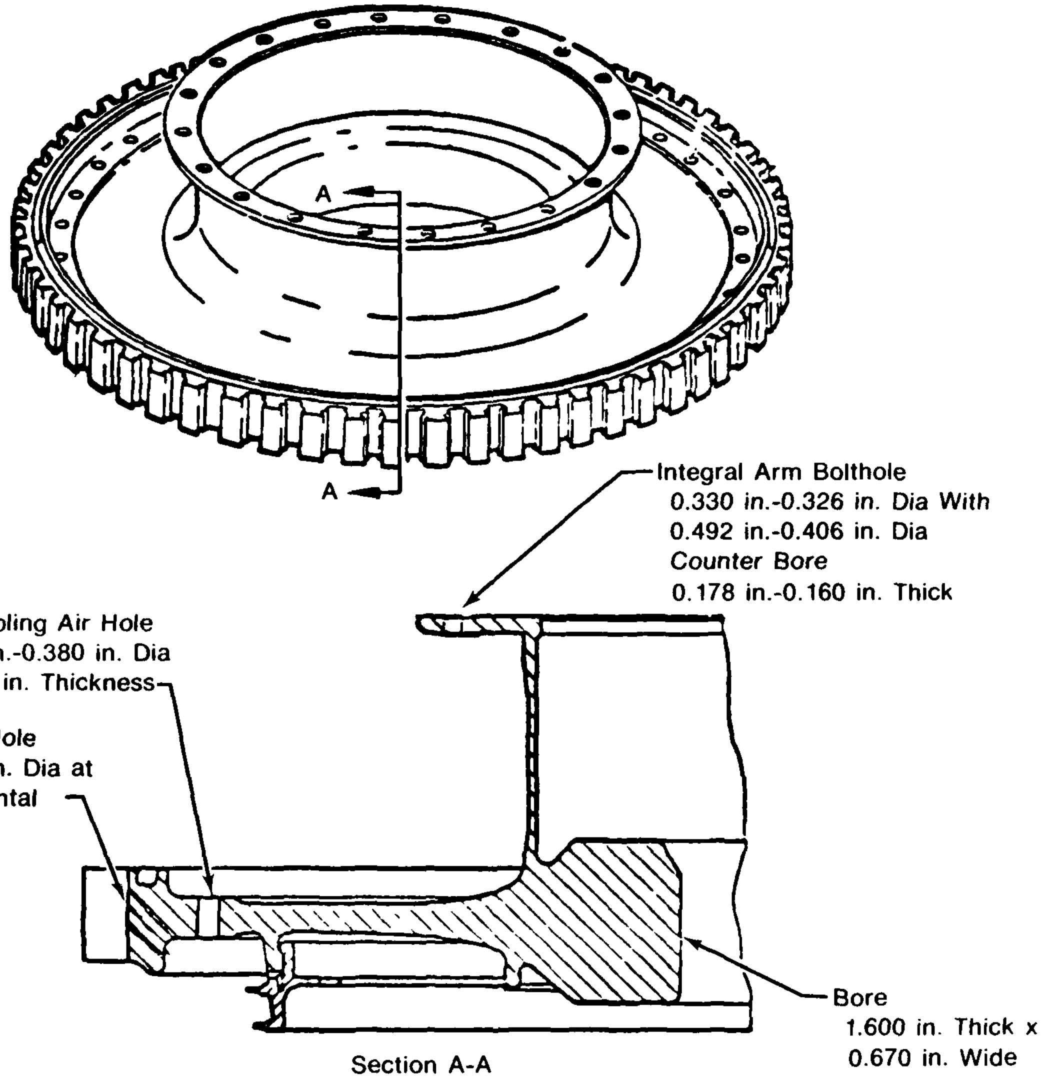


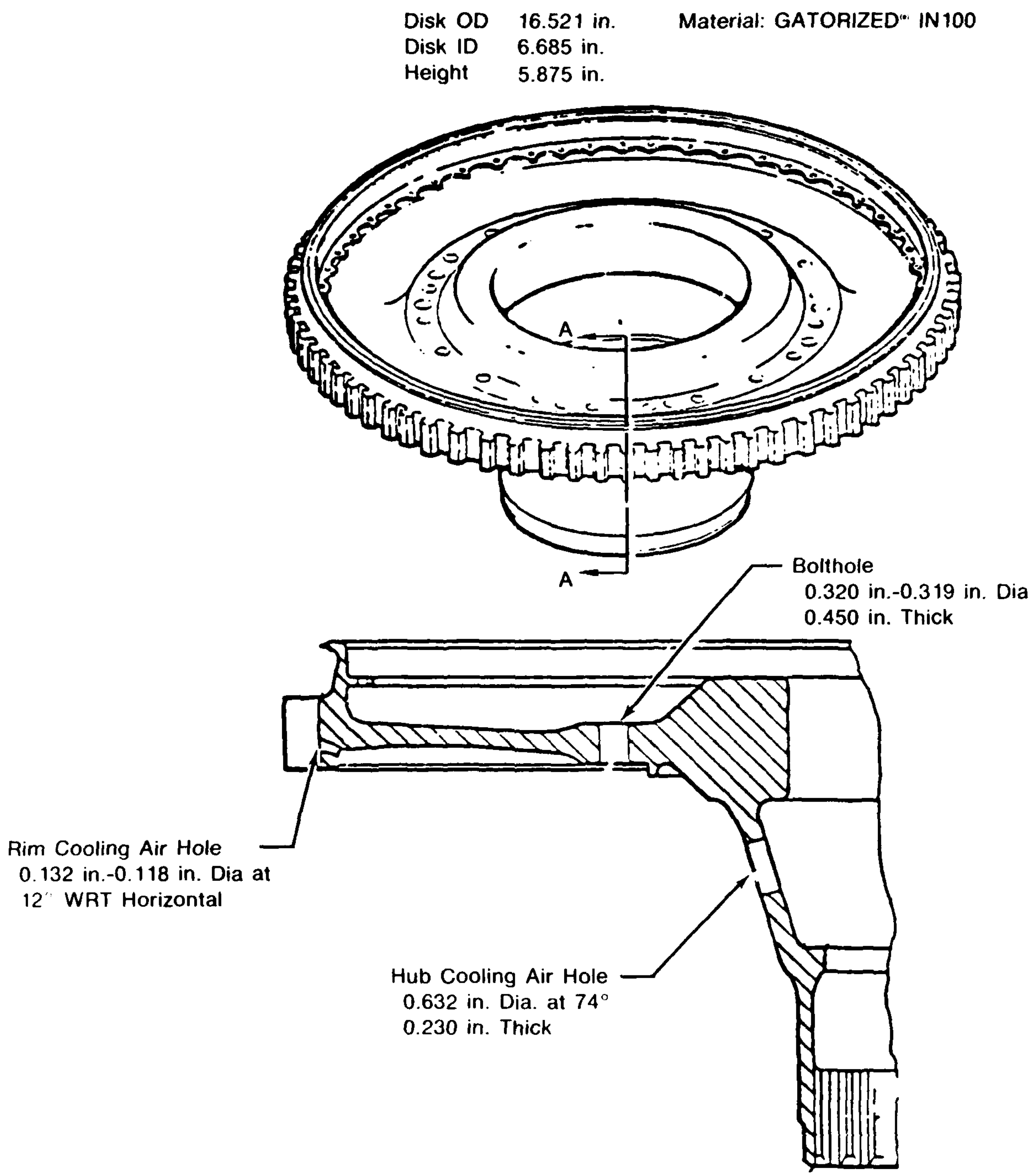
Figure F-14. 12th-Stage Compressor Disk (P/N 4022612)



Disk OD	18.368 in.	Material: GATORIZED® IN100
Disk ID	6.995 in.	
Height	3.832 in.	

FD 223594

Figure F-15. 1st-Stage Turbine Disk (P/N 4043321)



Section A-A

FD 223595

Figure F-16. 2nd-Stage Turbine Disk (P/N 4042922)

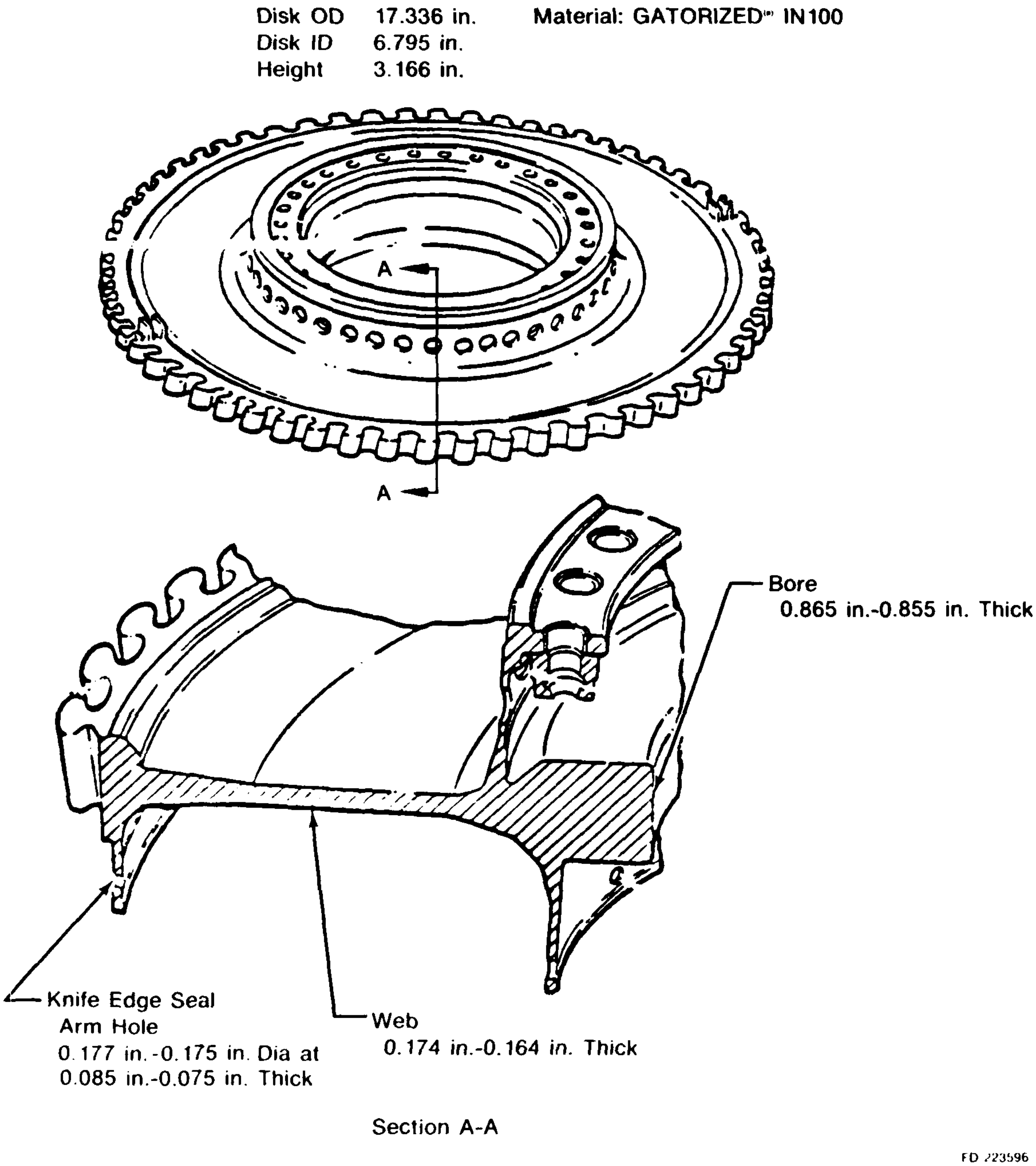


Figure F-17. 3rd-Stage Turbine Disk (P/N 4041794)

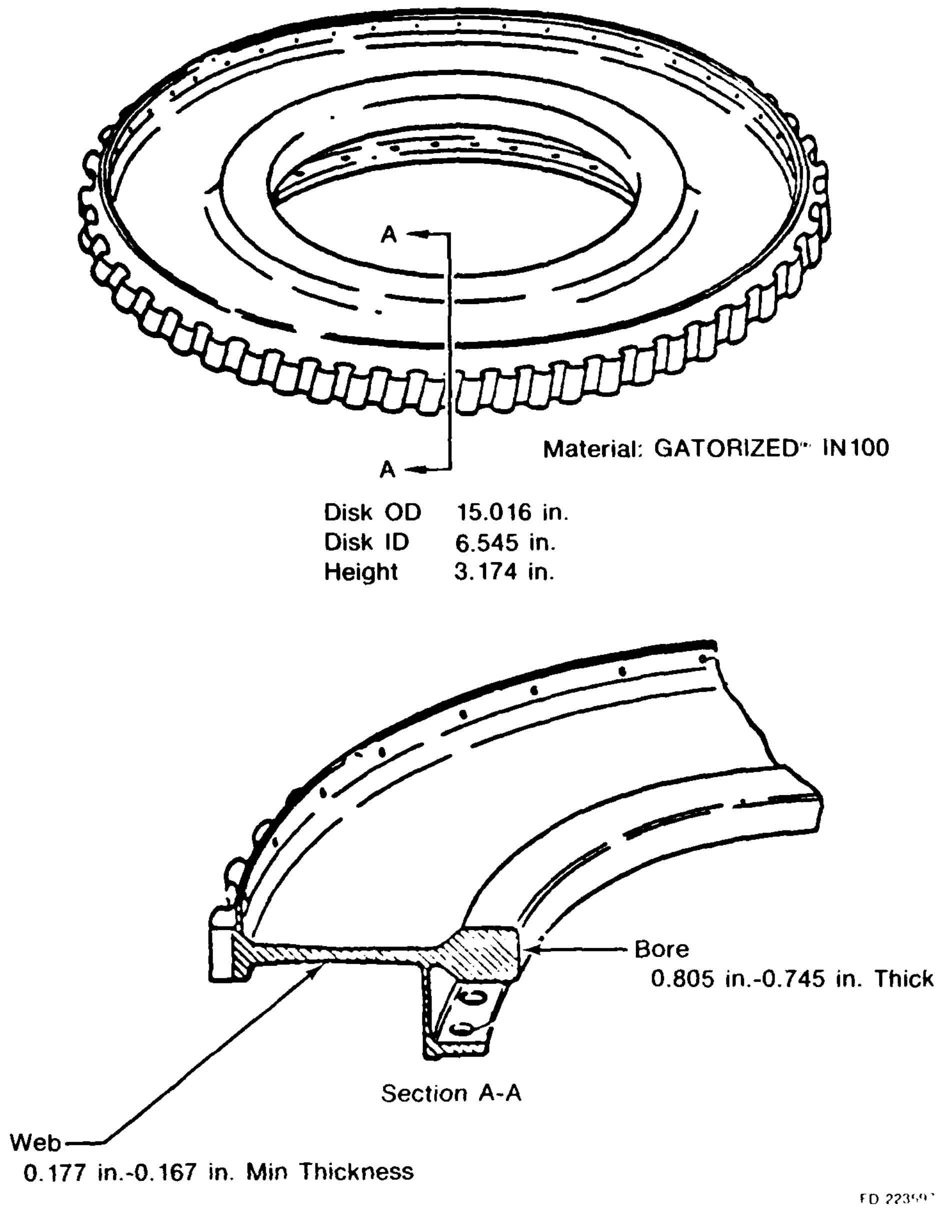


Figure F-18. 4th-Stage Turbine Disk (P/N 4061857)

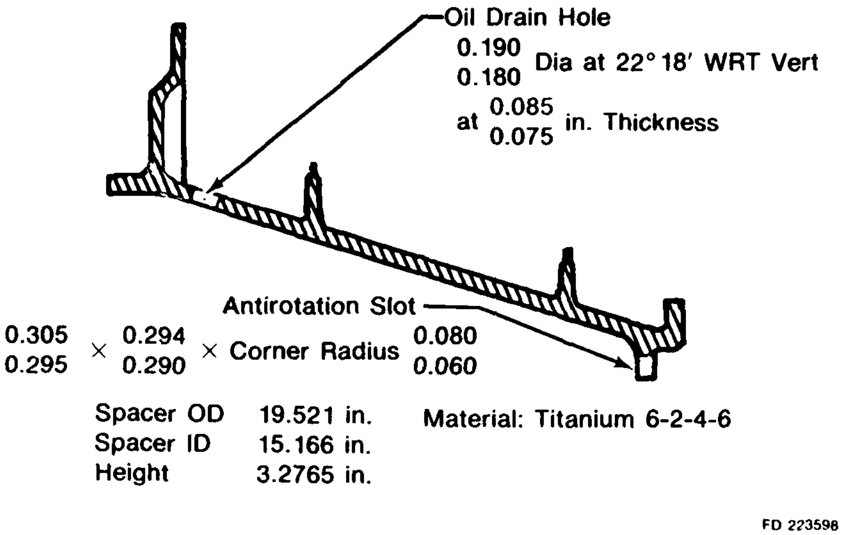


Figure F-19. 2-3 Compressor Spacer (P/N 4049087)

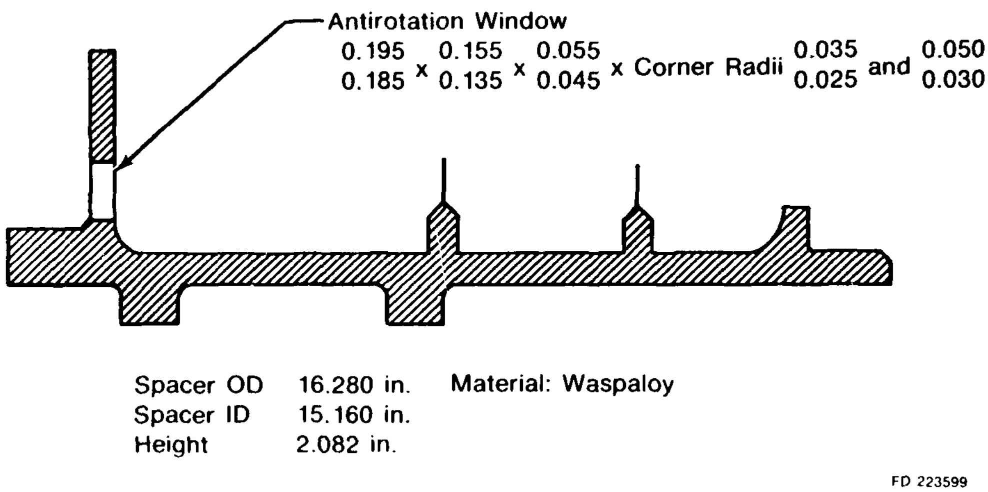


Figure F-20. 6-7 Compressor Spacer (P/N 4039846)

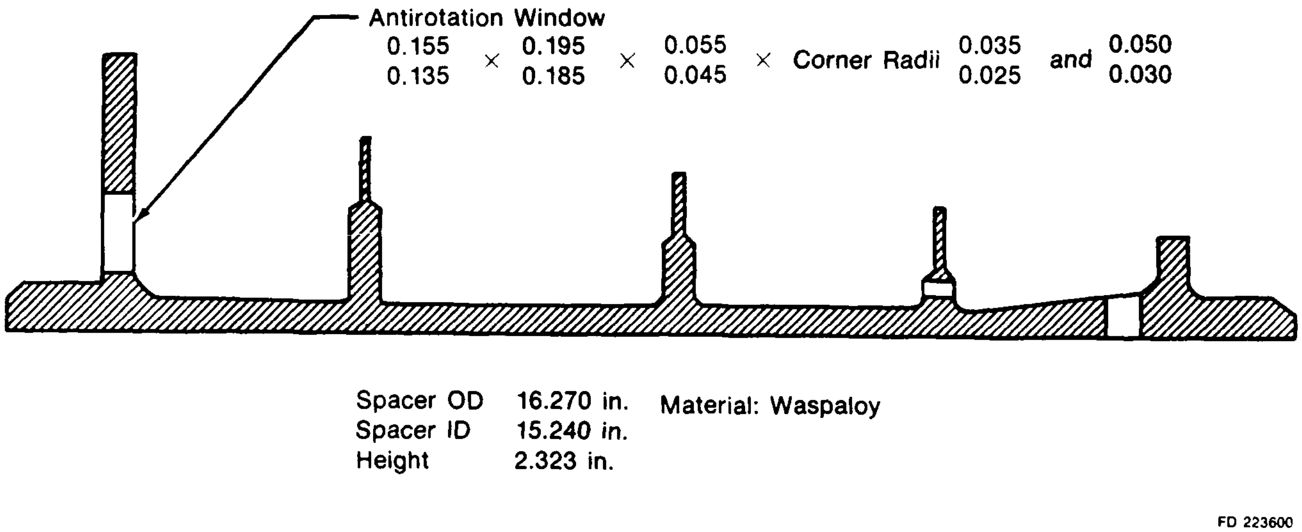
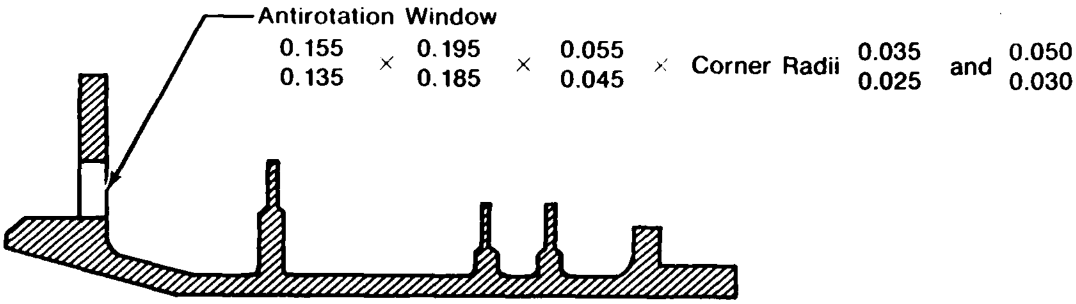


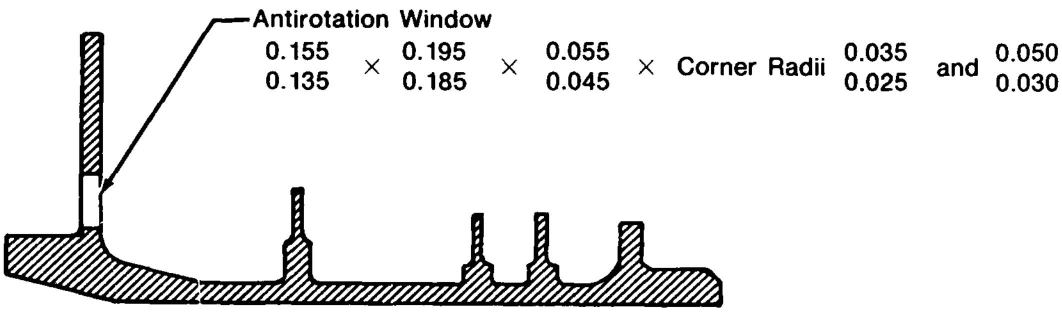
Figure F-21. 7-8 Compressor Spacer



Spacer OD 16.270 in. Material: Waspaloy
Spacer ID 15.240 in.
Height 1.760 in.

FD 223051

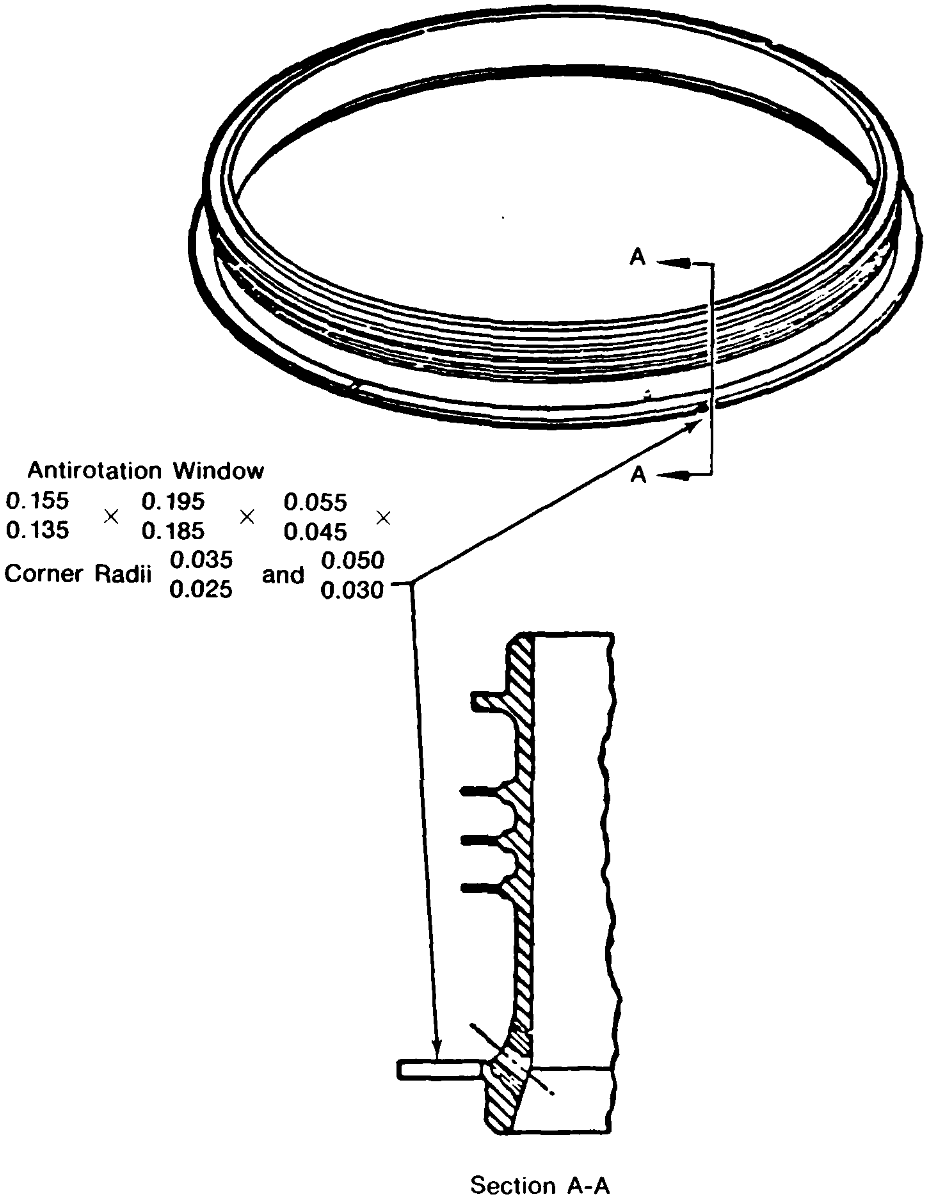
Figure F-22. 8-9 Compressor Spacer (P/N 4050978)



Spacer OD 16.330 in. Material: Waspaloy
Spacer ID 15.450 in.
Height 1.763 in.

FD 223052

Figure F-23. 9-10 Compressor Spacer (P/N 4050979)



Spacer OD 16.320 in.-16.300 in. Material: Astroloy
Spacer ID 15.470 in.-15.450 in.
Height 1.703 in.

FD 223053

Figure F-24. 10-11 High Pressure Compressor Spacer (P/N 4043279)

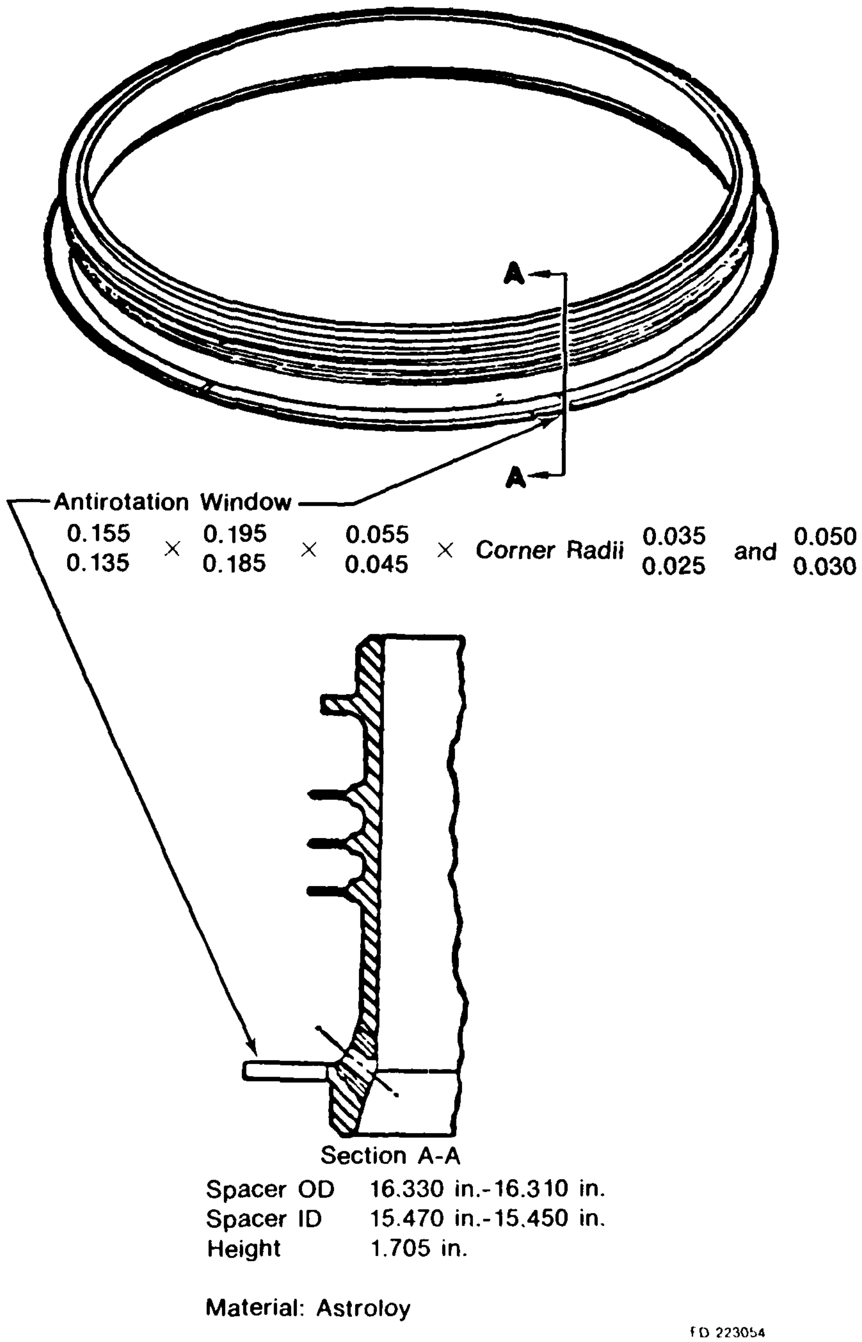
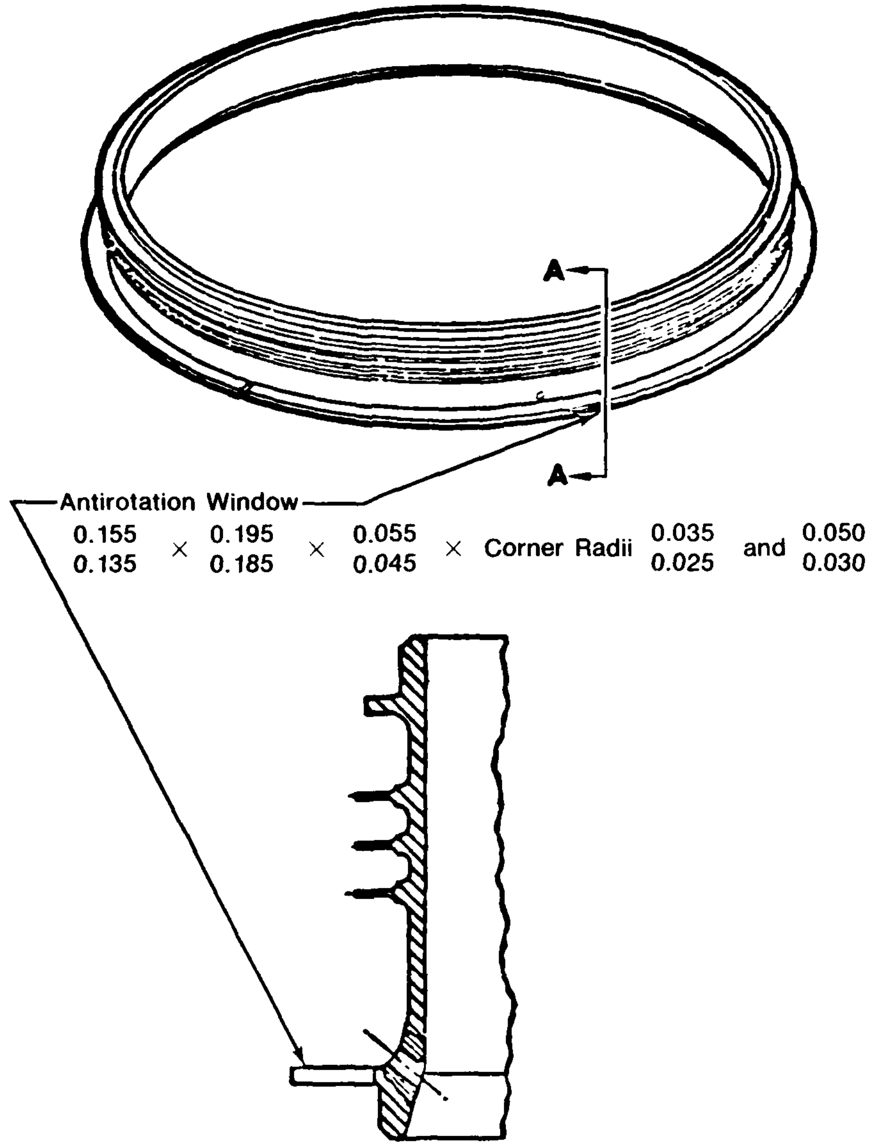


Figure F-25. 11-12 High Pressure Compressor Spacer (P/N 4043280)



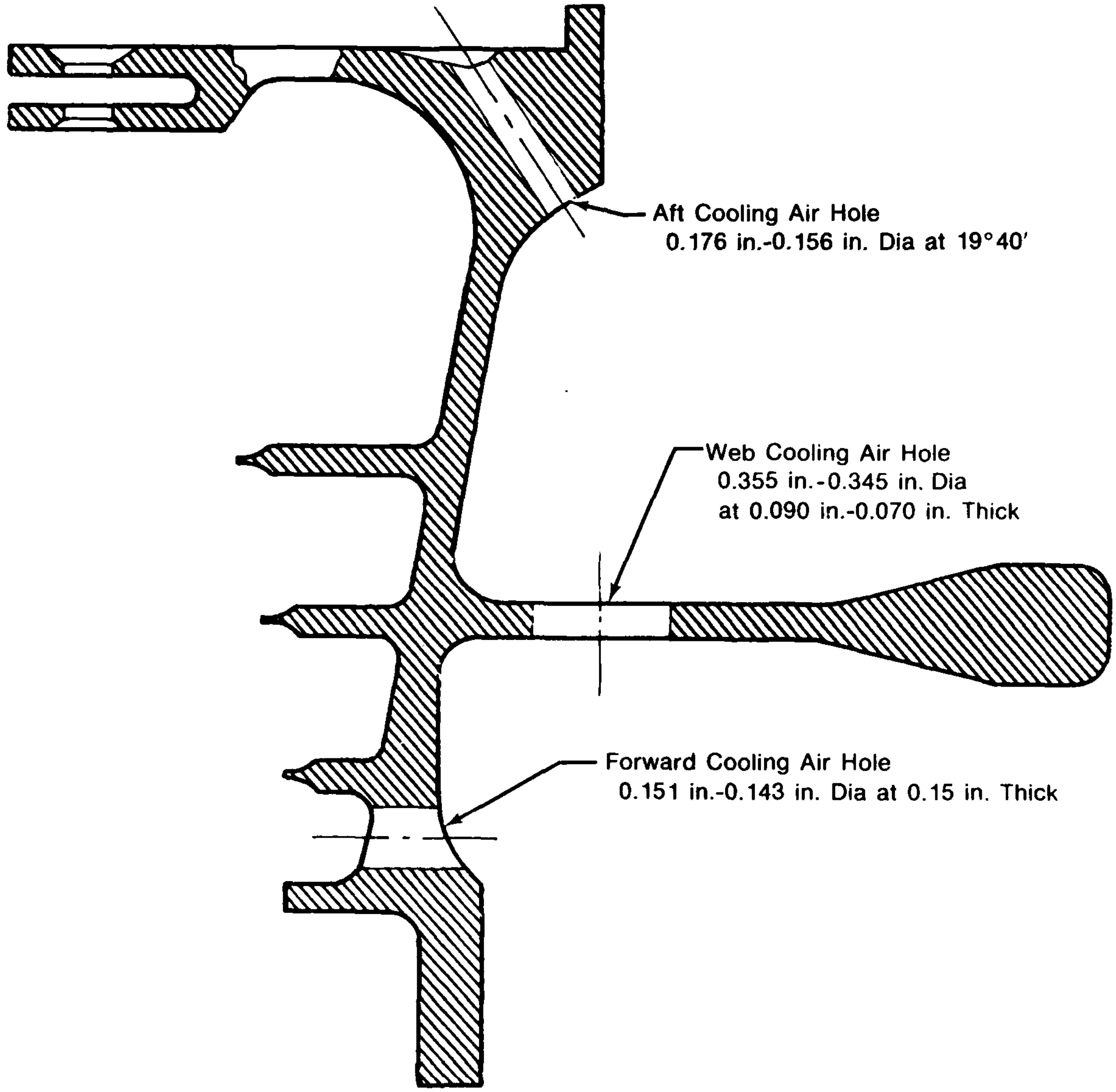
SECTION A–A

Spacer OD	16.330 in.-16.320 in.
Spacer ID	15.450 in.-15.470 in.
Height	1.612 in.

Material: Astroloy

FD [illegible]3055

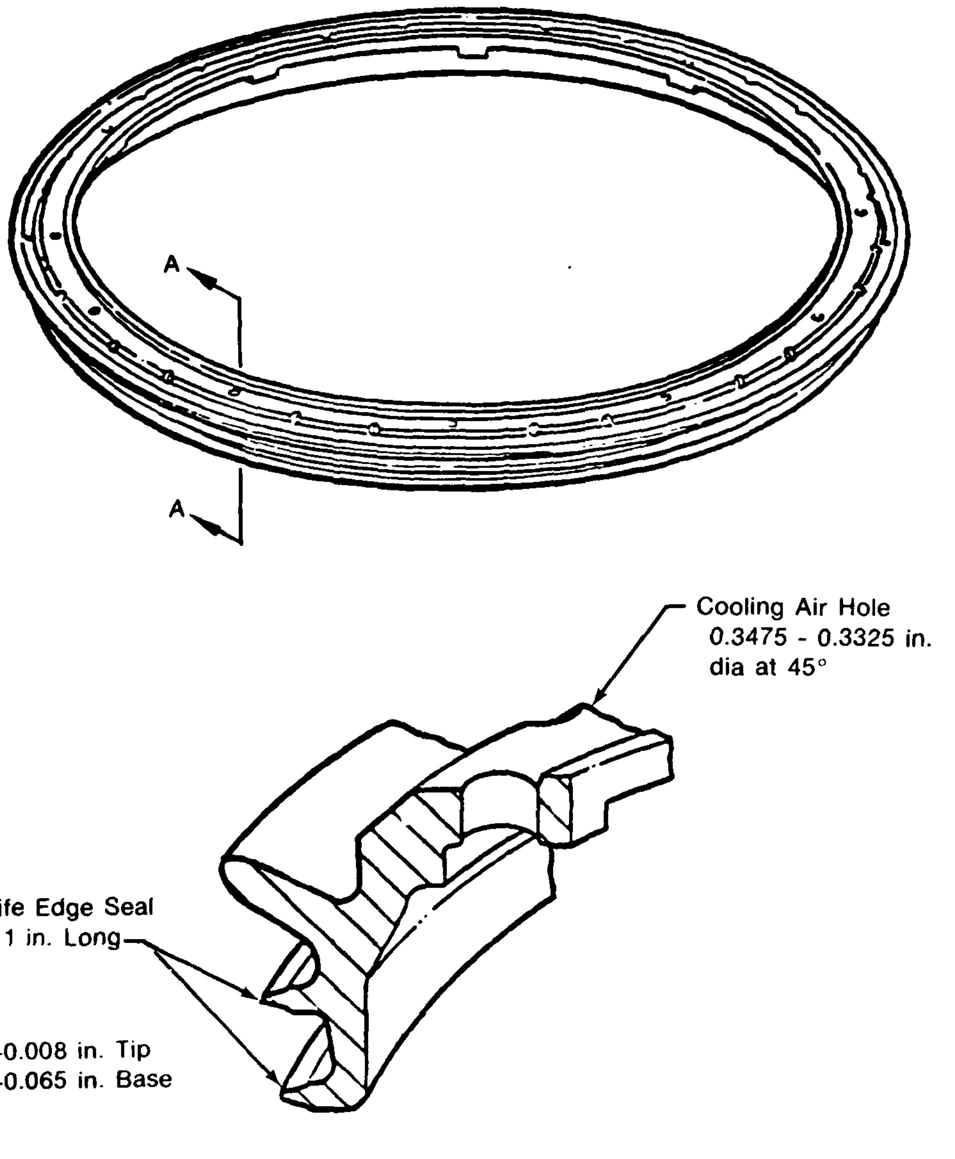
Figure F-26. 12-13 High Pressure Compressor Spacer (P/N 4041591)



Spacer OD	18.863 in.	Material: GATORIZED™ IN100
Spacer ID	13.395 in.	
Height	2.745 in.	

FD 223056

Figure F-27. High Pressure Turbine 1-2 Spacer (P/N 4042715)



Seal OD	17.735 in.-17.725 in.	Material: Astroloy
Seal ID	15.575 in.-15.565 in.	
Seal Height	1.250 in.	

FD 223057

Figure F-28. High Pressure Turbine Tangential on Board Injector Outside Diameter Seal (P/N 4036812)

AD-A167 022 RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN VOLUME 2 3/4
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BEACH FL GOVERNMENT PRODUCTS DIV.. J S CARGILL ET AL.
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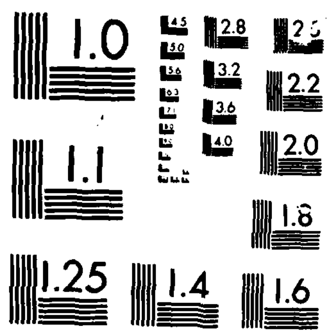

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RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX G
INSPECTION PERFORMANCE SPECIFICATION

Prepared by:

C. A. Rau, Jr.
S. W. Hopkins
P. M. Besuner
Failure Analysis Associates

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P.O. Box 2691
West Palm Beach, Florida 33402

APPENDIX G

INSPECTION PERFORMANCE SPECIFICATION

Formulation of a final specification will not be made until the probabilistic Retirement for Cause (RFC) software has been used to perform sensitivity analyses of candidate F100 components.

Pending completion of these analyses, the following preliminary specification is proposed:

1) For each of the material/part geometry/flaw type, the system must be demonstrated to provide sufficient *reliability* (probability of rejecting a cracked part) at three defect size ranges:

   a) Acceptable cracks — which will definitely not grow to failure in several inspection intervals.

   b) Marginal cracks — at approximately the optimum accept/reject size.

   c) Unacceptable cracks — which could grow to failure over one inspection interval.

2) In addition, the *false rejection probability* must be sufficiently low at all three actual defect size ranges.

It is important to point out that the specific size ranges must be determined for each location and flaw type by means of the RFC analysis. Full probabilistic analysis will establish the optimum accept/reject size(s), but our experience indicates that this will occur at a crack size which will grow to failure under average loading and environmental conditions in three to five inspection intervals (i.e., a safety factor, SF, of 3 to 5). The unacceptable crack size to be evaluated is one that will have a high probability of growing to failure in one inspection interval if it were returned into service. Because the deterministic fracture mechanics analyses performed in the Structural Assessment Program have some degree of conservatism built into them, they will not be used directly, without modification, to establish the optimum (accept/reject) size nor the smaller or larger size ranges where inspection reliability is to be evaluated.

That probabilistic reliability which is sufficient shall be finalized by the sensitivity analyses with the RFC software. Inspection reliability goals are shown in Figure G-1. They are:

Crack Size	*Probability of Rejection*
Acceptable	Less than 0.255
($a \ll s$, $SF > 6$)	
Optimum	Greater than 0.50
($a \simeq s$, $SF = 3$)	
Unacceptable	Greater than 0.905
($a \gg s$, $SF = 1$)	

(Where a is actual flaw size and s is accept/reject inspection level.)

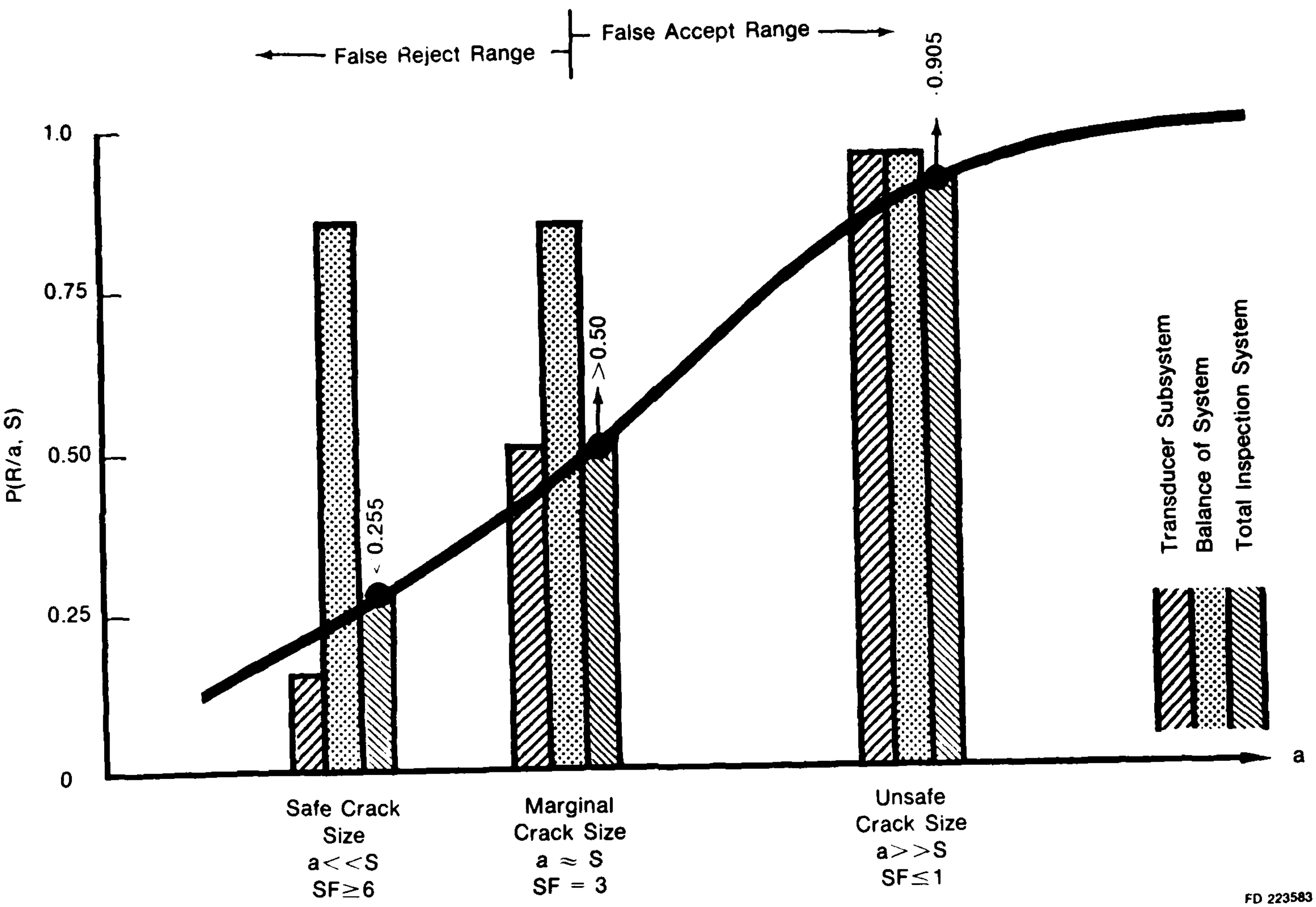

Figure G-1. Initial Recommendations for Probability of Rejection Specifications at Various Cracks Sizes, a

For the preliminary specification, the probability of rejection for optimum and unacceptable (large) cracks must exceed 0.50 (50%) and 0.905 (90%), respectively. On the other hand, for acceptable (small) cracks the specification requires that no more than 0.255 (25%) of the cracks are rejected in order to assure an acceptably low number of false rejections.

Due to the anticipated availability date for total system evaluation under actual depot conditions, an evaluation of the transducer/electronics (or penetrant reading device) subsystem prior to assembly and evaluation of the balance of the inspection system (e.g., manipulators, position locations, vibration, operator errors) is required. Figure G-1 shows the preliminary specification for the transducer/electronics subsystem as well as for the balance of the system and the total system.

The evaluation procedure will use at least 10 actual cracks of each size range for each material, defect type, and geometric detail. The same part can be used to produce cracks and evaluate inspection performance in different locations and reduce the total number of parts required.

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX H
PARTS HANDLING SUBSYSTEM SPECIFICATION

Prepared by:

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J. Oosterlink
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APPENDIX H

PARTS HANDLING SUBSYSTEM FOR RETIREMENT FOR CAUSE INSPECTION SYSTEM

1. SCOPE

The parts handling systems are presented under three approaches based on different parts throughput rates. A condensed description of these approaches follows:

System I — This system is configured to process RFC-candidate disks and spacers for 100 P&WA F100 engines per month. Parts loading and unloading and setup on the inspection machines will be manual. Each machine is totally automatic and suitable to inspect any of the parts.

System II — This system is configured to process RFC-candidate disks and spacers for 200 P&WA F100 engines per month with fully automatic operations. Machines are typically dedicated to one type of inspection except when requirements are low. In this case the machine is set up for more than one type of inspection.

Pilot System — This system is configured with two eddy current and one ultrasonic inspection machines. The purpose is to set up a minimal operation to test and verify systems capabilities.

This specification defines the minimum technical and performance requirements for handling disks and spacers for gas turbine engines. The equipment will be suitable for use in the existing repair facility depot at the U.S. Air Force. The three systems used for this analysis are not exclusive. They were chosen because they represent the range of probable system requirements.

The parts handling systems will be provided for transport of gas turbine engine disks and spacers totalling 21 parts per engine. The parts are grouped in four modules as follows:

Module	*Part Description*	*ID*	*Part No.*
I. Fan Module	1st Disk	1F	4046741
	2nd Disk	2F	4048902
	3rd Disk	3F	4048903
II. Compressor Sub-Module	4th Disk	4C	4030604
	7th Disk	7C	4041337
	8th Disk	8C	4040108
	12th Disk	12C	4022612
	2-3 Spacer	2/3 CPS	4049087
	6-7 Spacer	6/7 CPS	4039846
	7-8 Spacer	7/8 CPS	4039727
	8-9 Spacer	8/9 CPS	4050978
	9-10 Spacer	9/10 CPS	4050979
	10-11 Spacer	10/11 CPS	4043279
	11-12 Spacer	11/12 CPS	4043280
	12-13 Spacer	12/13 CPS	4041591

III.	High Turbine Sub-Module	1st Disk	1T	4043321
		2nd Disk	2T	4042922
		1-2 Spacer	1/2 TS	4042715
		TOBI Seal	TOBI	4036812
IV.	Low Turbine Module	3rd Disk	3T	4041794
		4th Disk	4T	4001857

Each part contains the part number and a unique serial number. The parts configuration and basic dimensions are illustrated in figures H-1 through H-21.

Time available for processing was established on the basis of a seven hour, one shaft per day operation, 22 days per month, for a total of 154 hr per month.

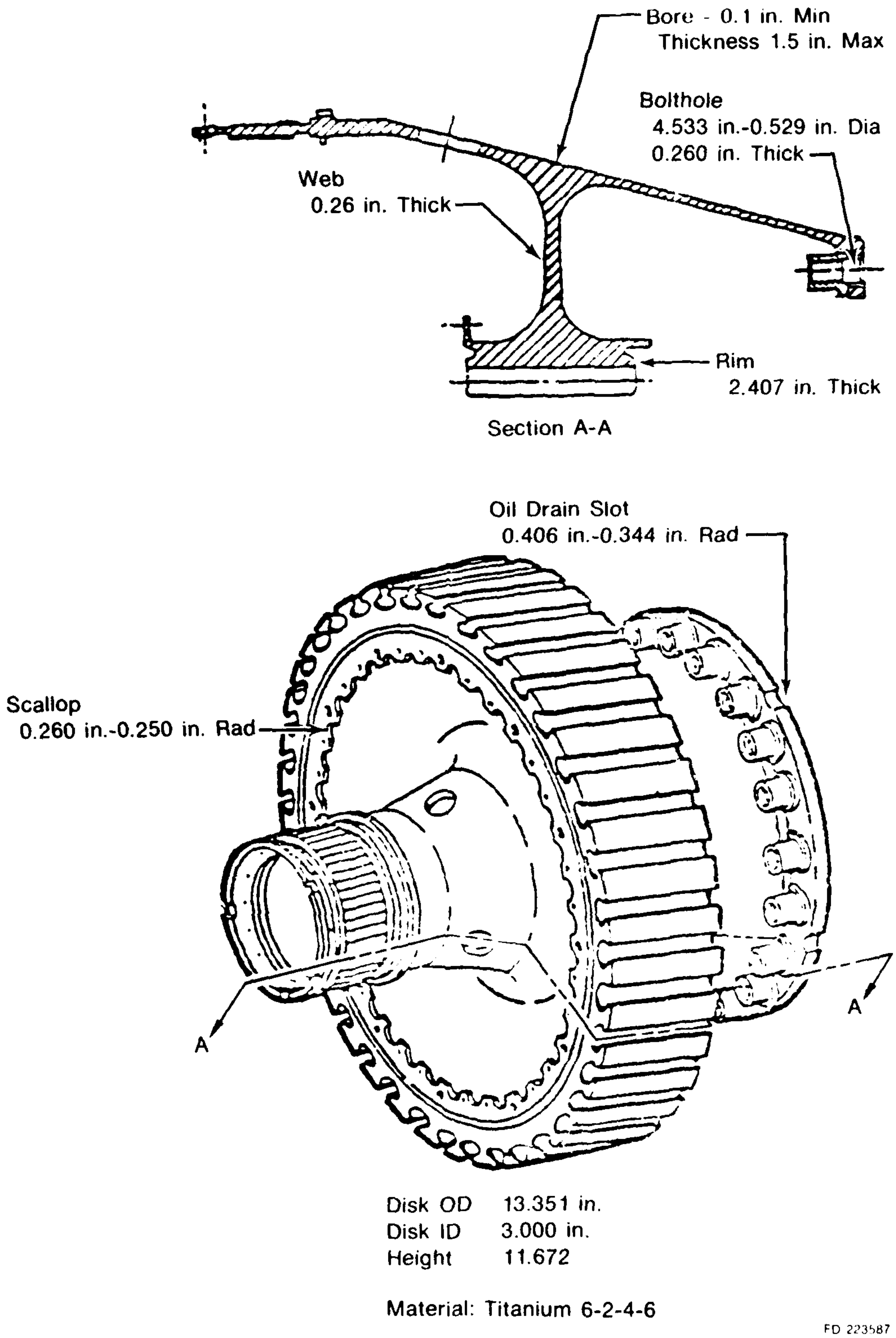


Figure II-1. 1st-Stage Fan Disk (P/N 4046711)

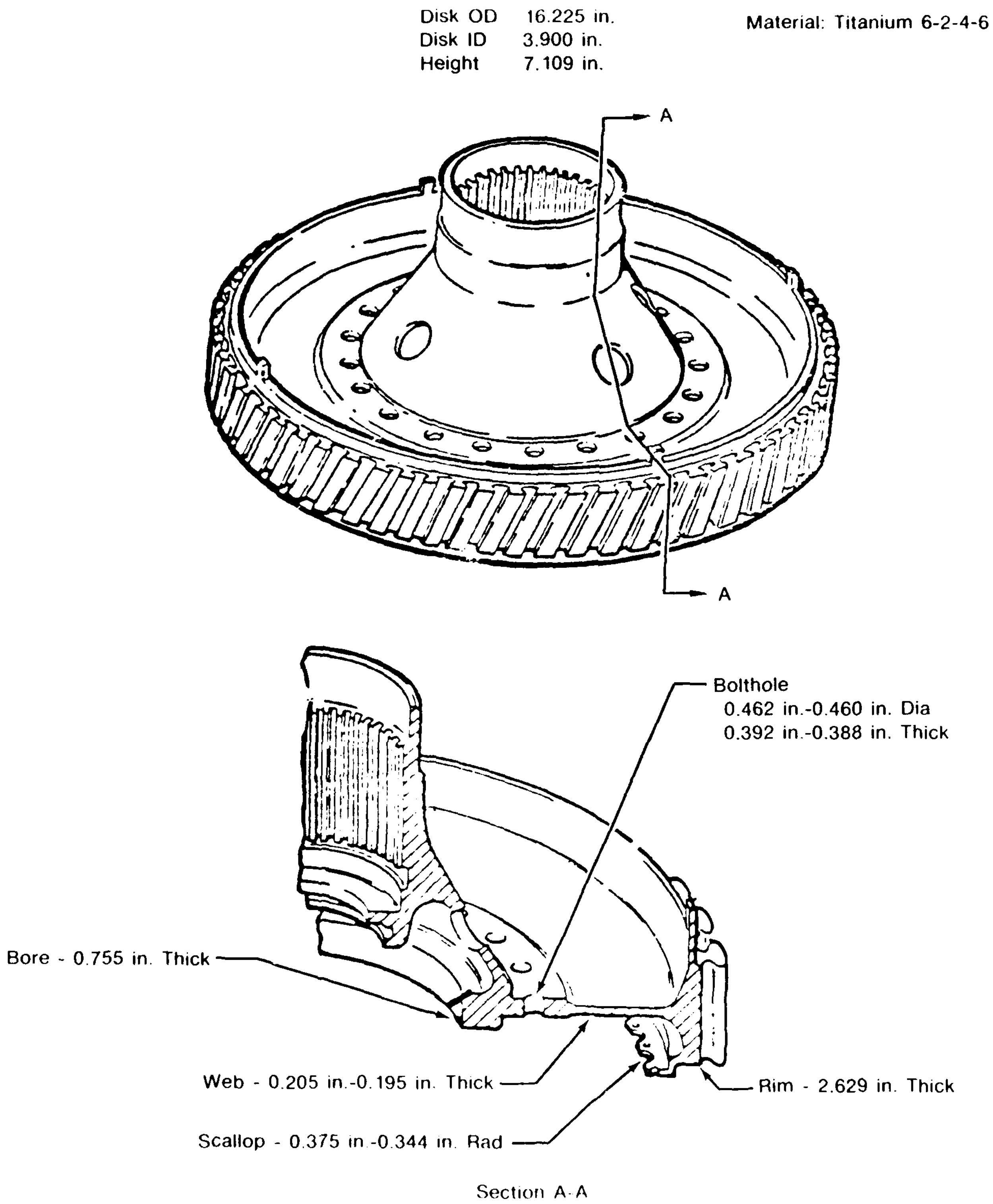


Figure II-2. 2nd-Stage Fan Disk (P/N 4048902)

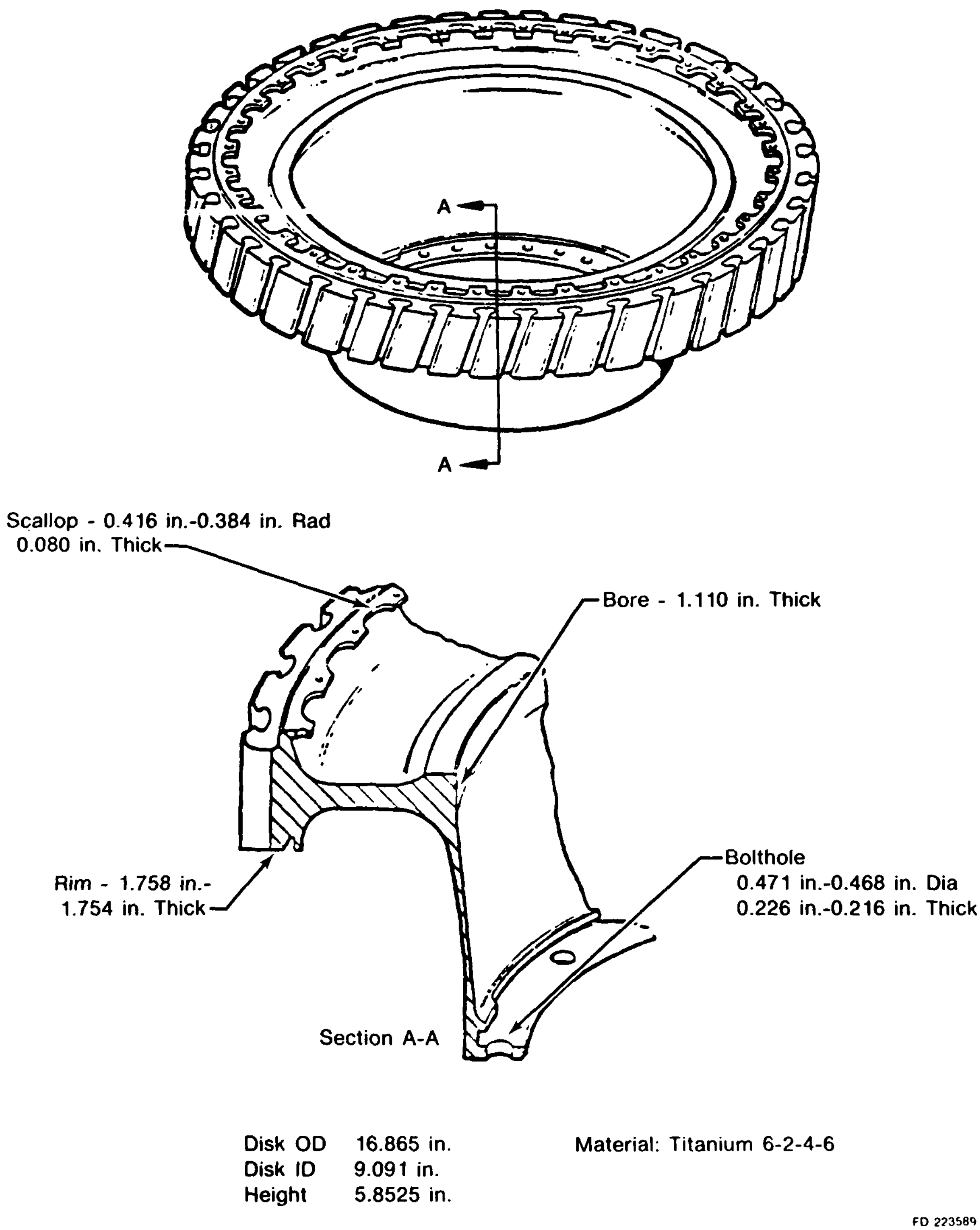
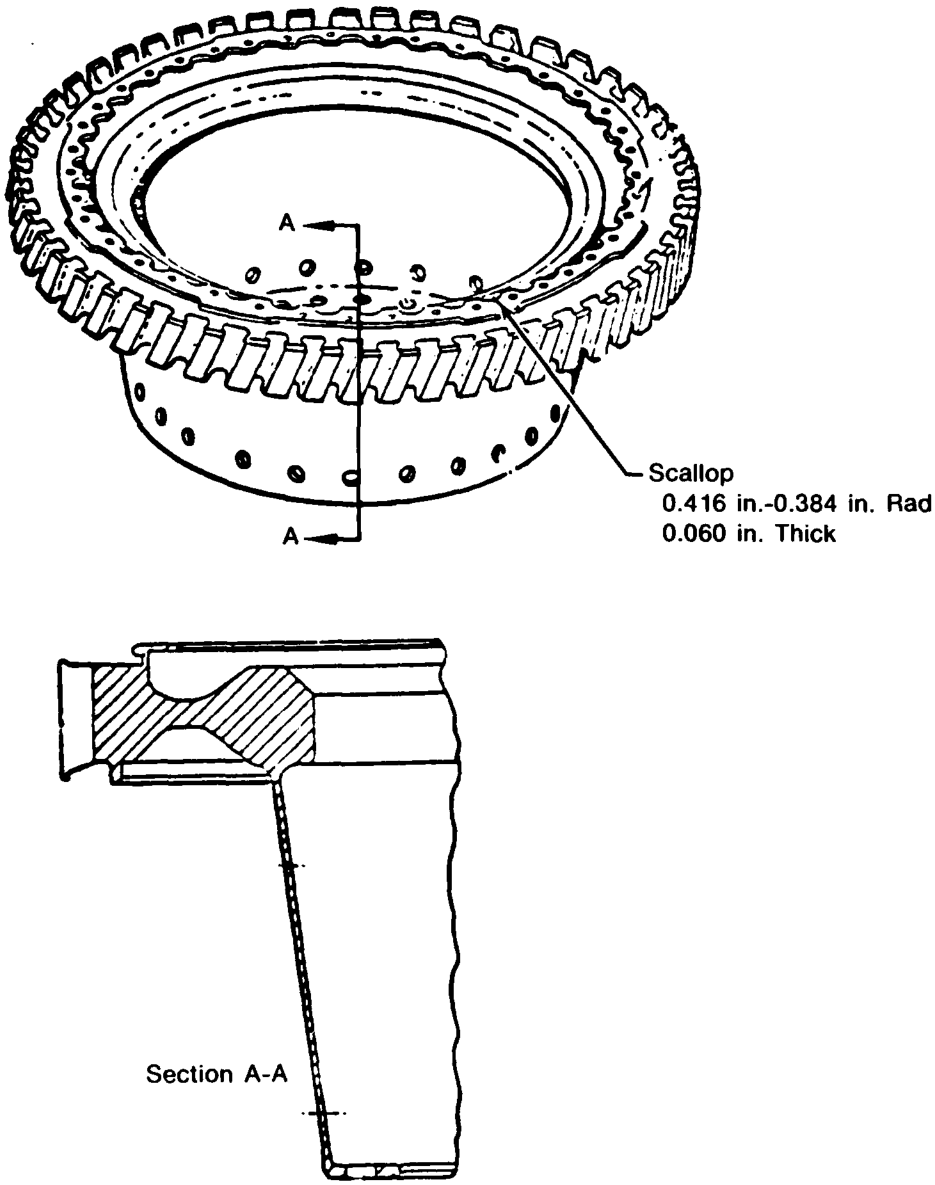


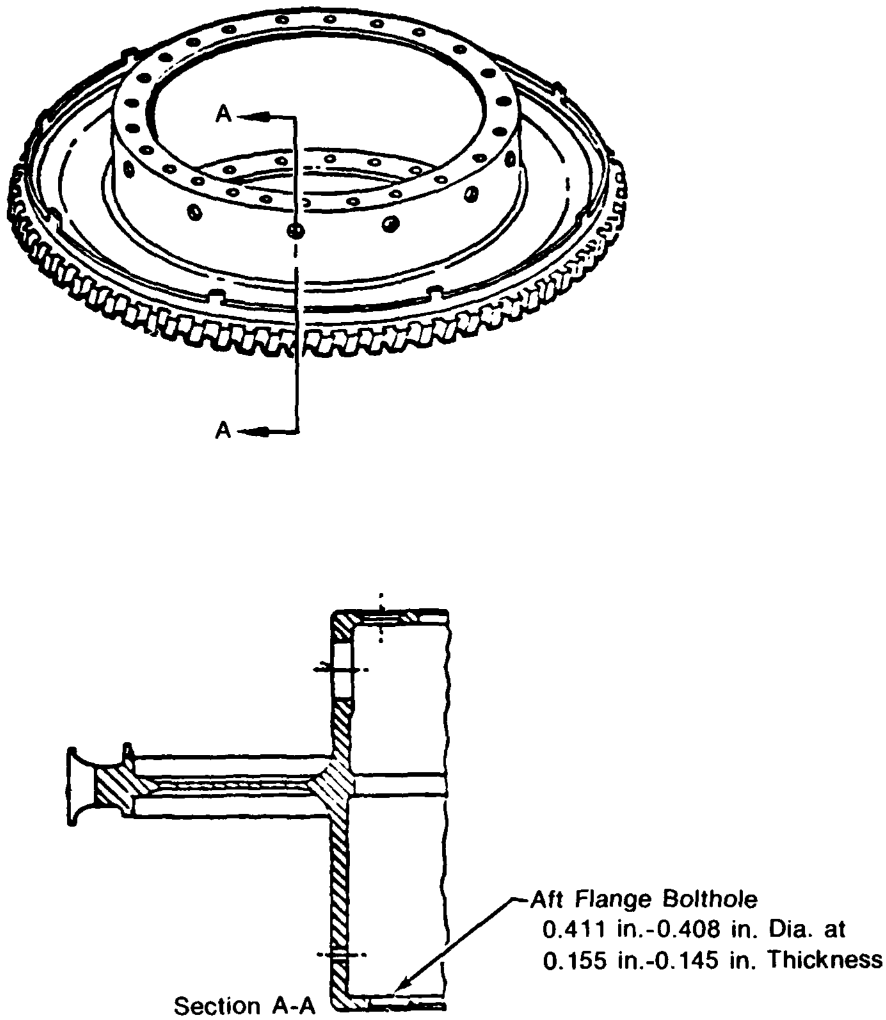
Figure II-3. 3rd-Stage Fan Disk (P/N 4048903)



Disk OD	16.865 in.	Material: Titanium 6-2-4-6
Disk ID	9.091 in.	
Height	6.220 in.	

FD 223590

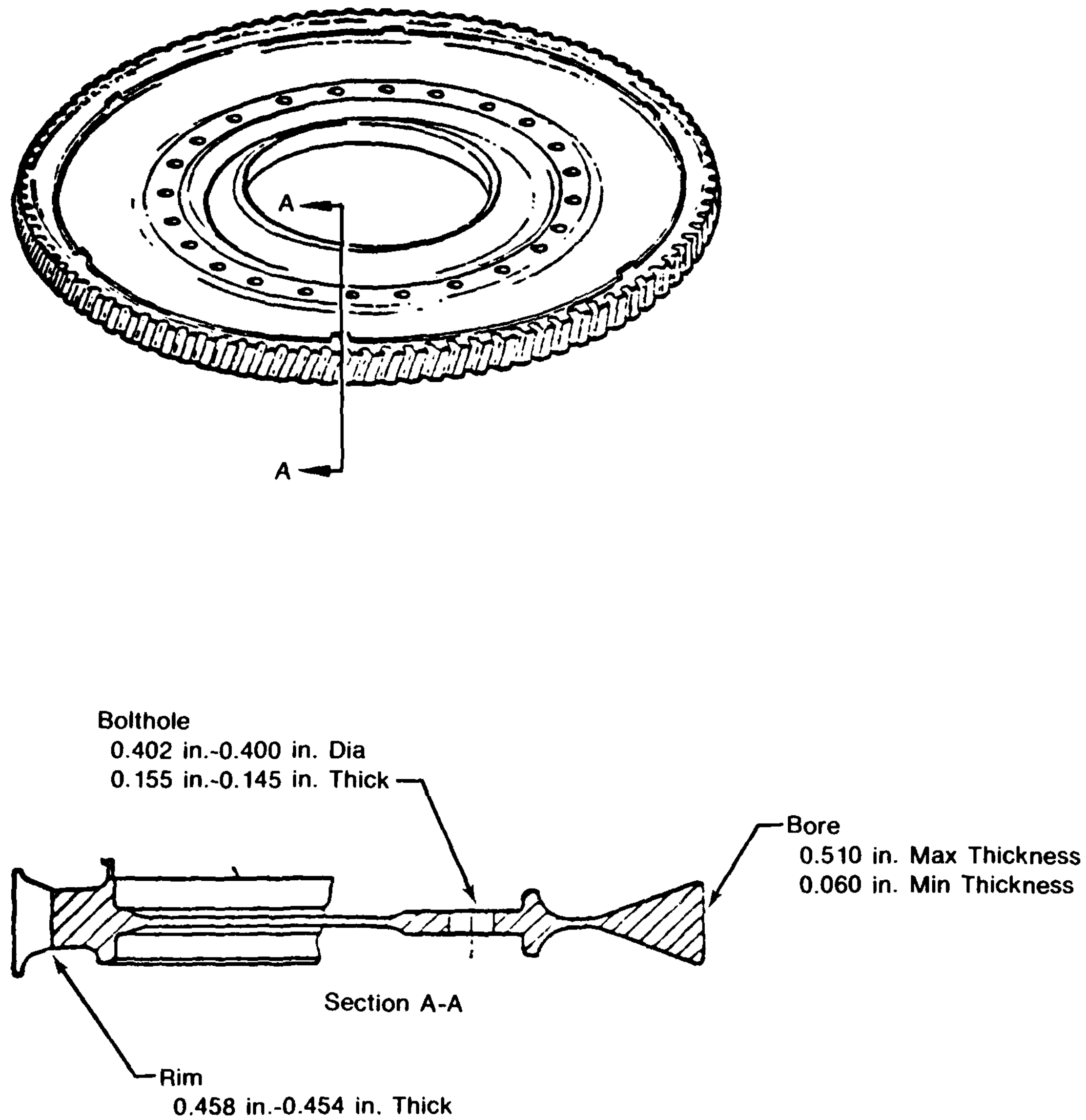
Figure H-4. 4th-Stage Compressor Disk (P/N 4030604)



Disk OD	16.776 in.	Material: Waspaloy
Disk ID	8.710 in.	
Height	4.499 in.	

FD 223591

Figure H-5 7th-Stage Compressor Disk (P/N 4011337)



Disk OD 16.863 in.
Disk ID 6.395 in.
Height 0.904 in.

Material: Waspaloy

Figure H-6. 8th-Stage Compressor Disk (P/N 4040108)

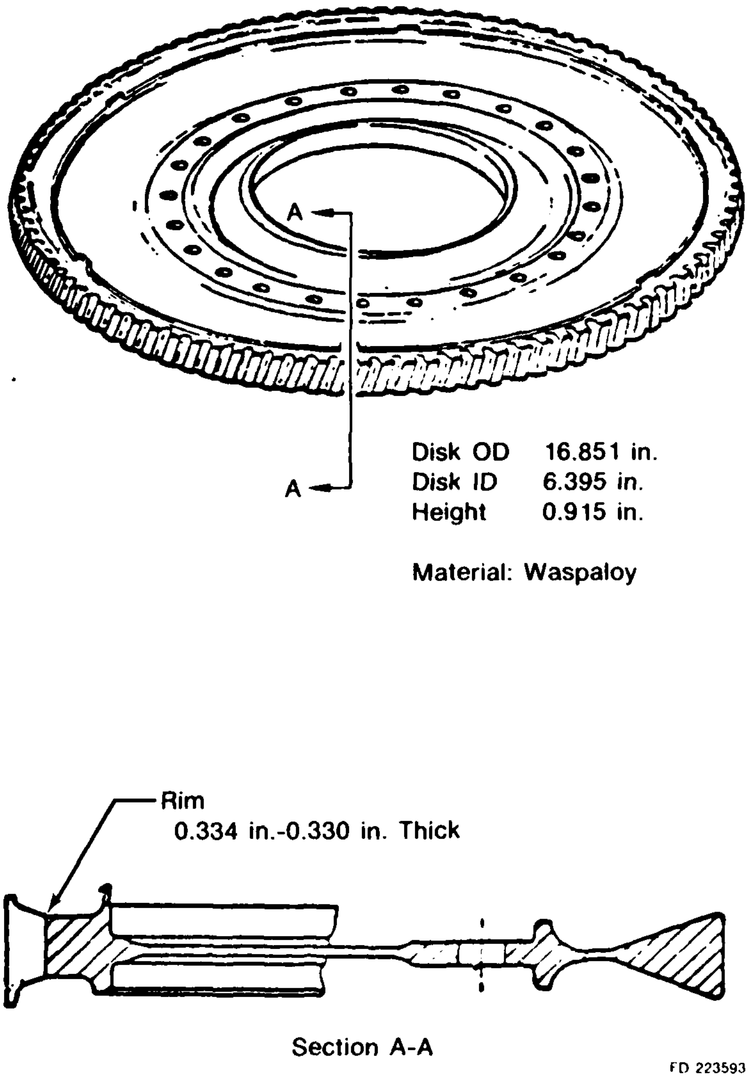
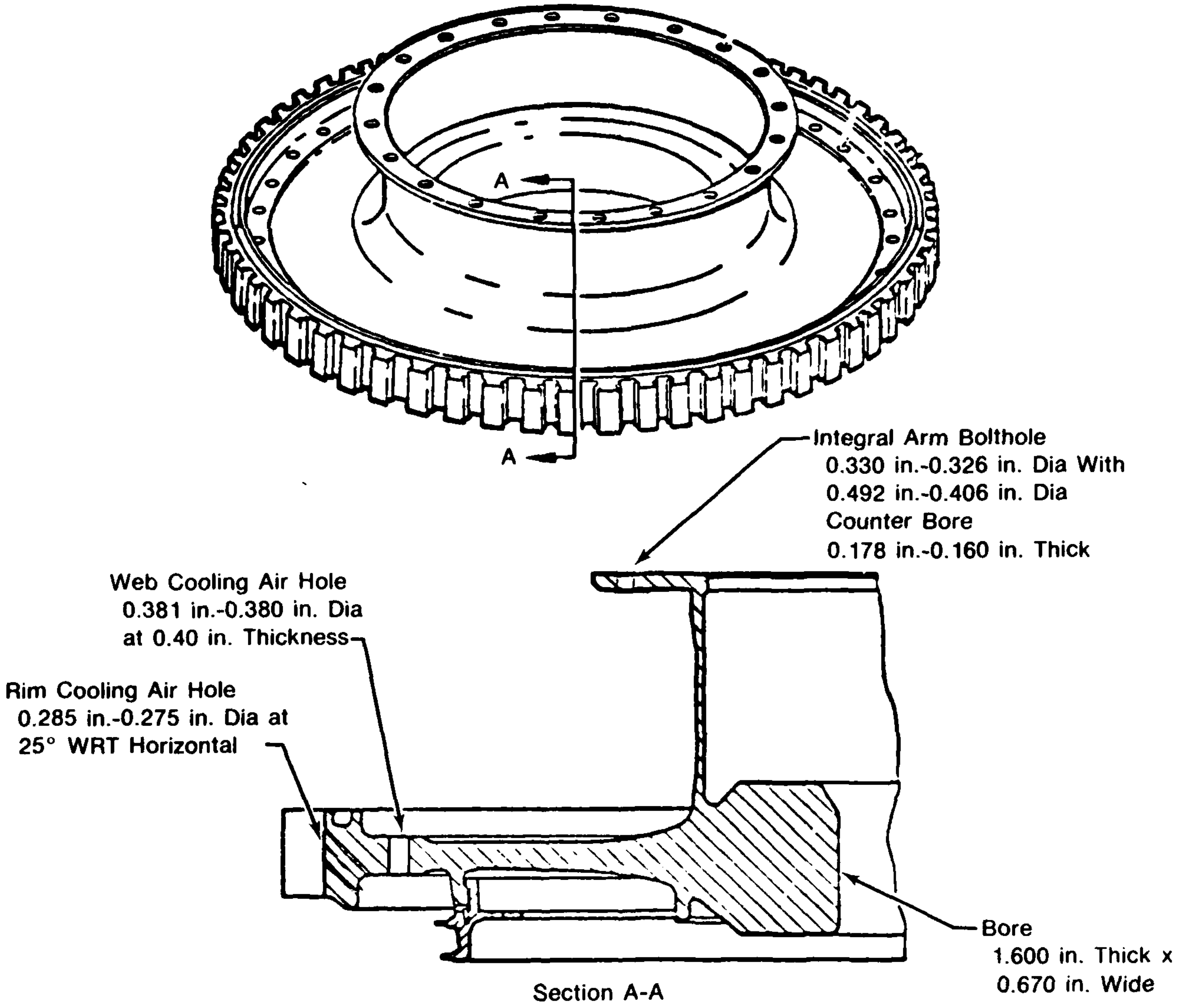


Figure H-7. 12th-Stage Compressor Disk (P/N 4022612)



Disk OD	18.368 in.	Material: GATORIZED™ IN100
Disk ID	6.995 in.	
Height	3.832 in.	

Figure H-8. 1st-Stage Turbine Disk (P/N 4043321)

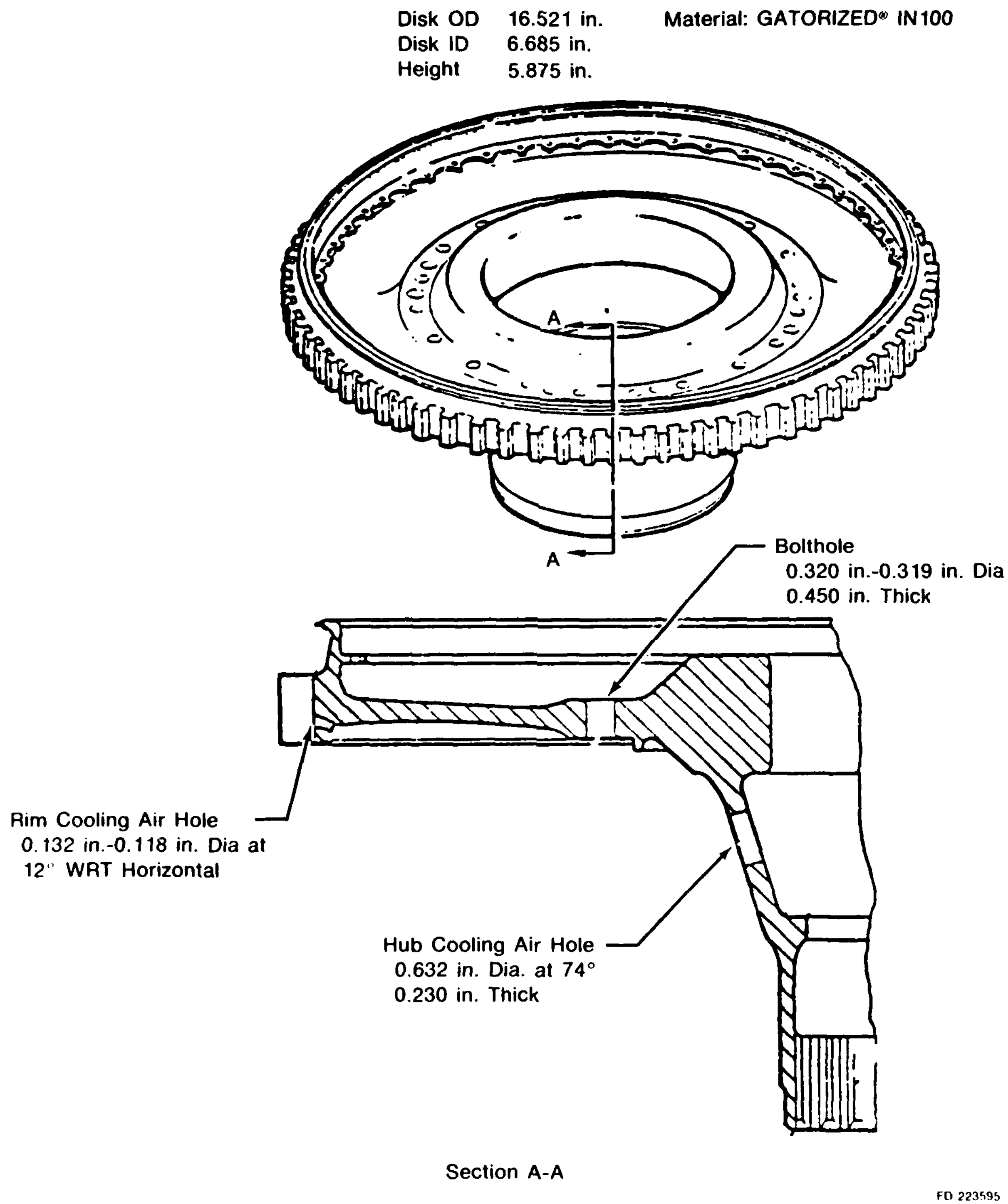


Figure H-9. 2nd-Stage Turbine Disk (P/N 4042922)

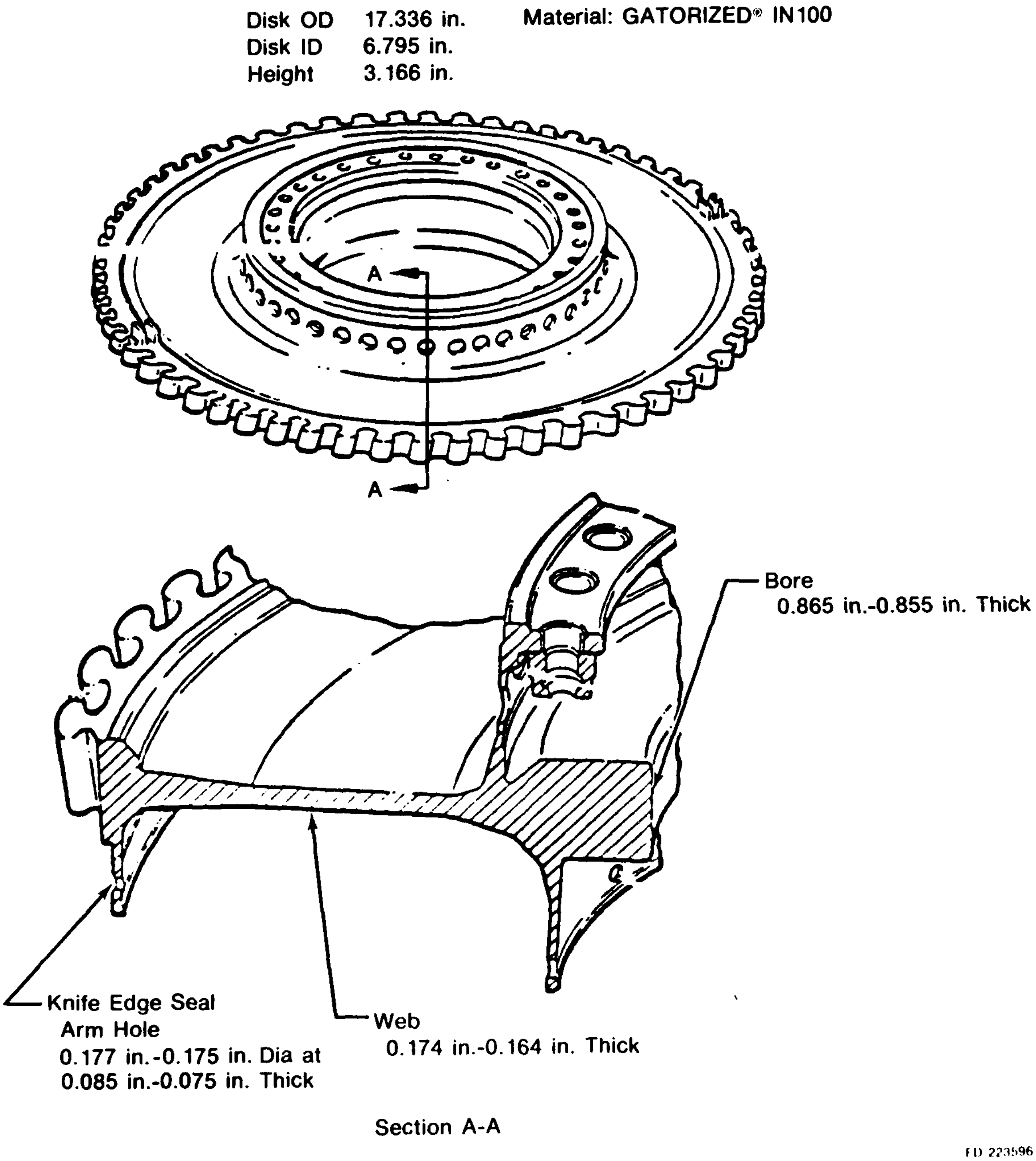


Figure H-10. 3rd-Stage Turbine Disk (P/N 4041794)

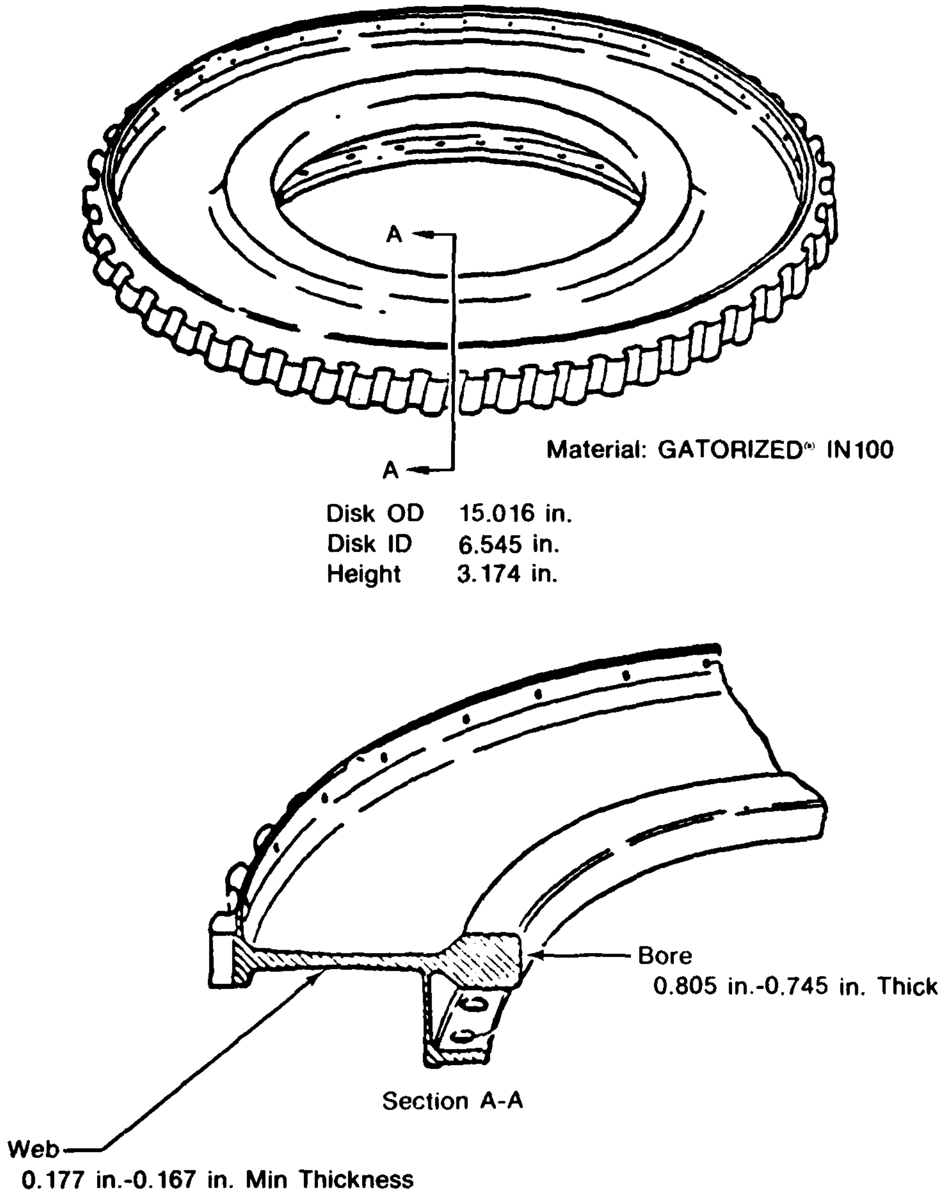


Figure H-11. 4th-Stage Turbine Disk (P/N 4061857)

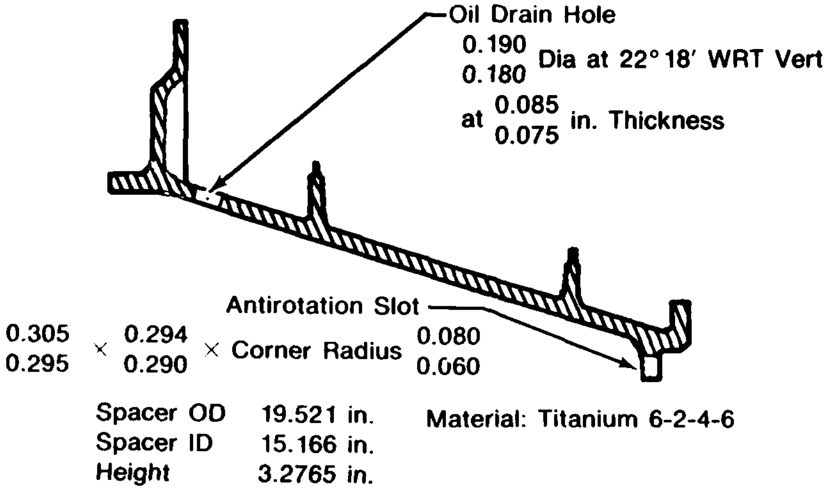


Figure H-12. 2-3 Compressor Spacer (P/N 4049087)

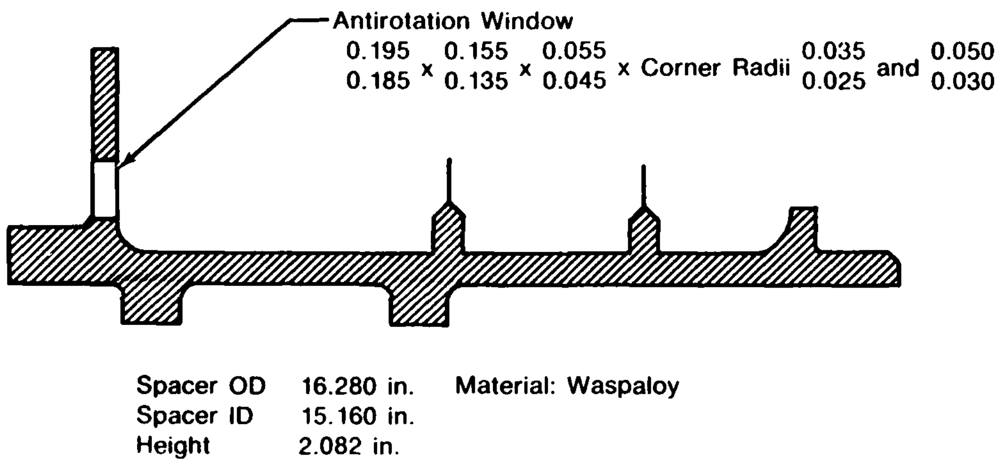


Figure H-13. 6-7 Compressor Spacer (P/N 4039846)

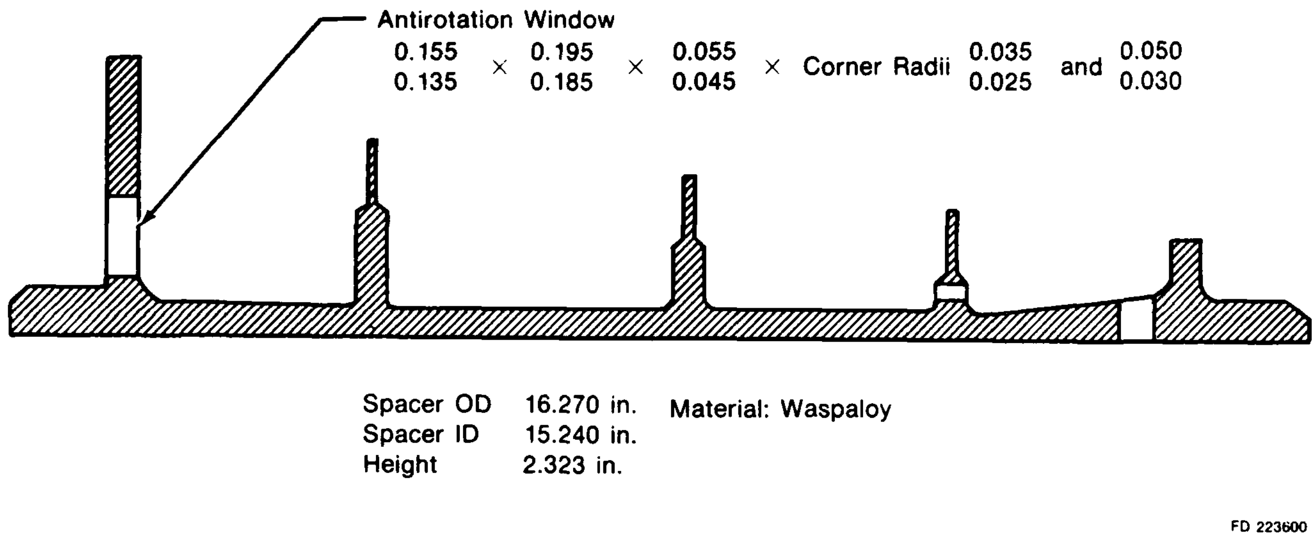
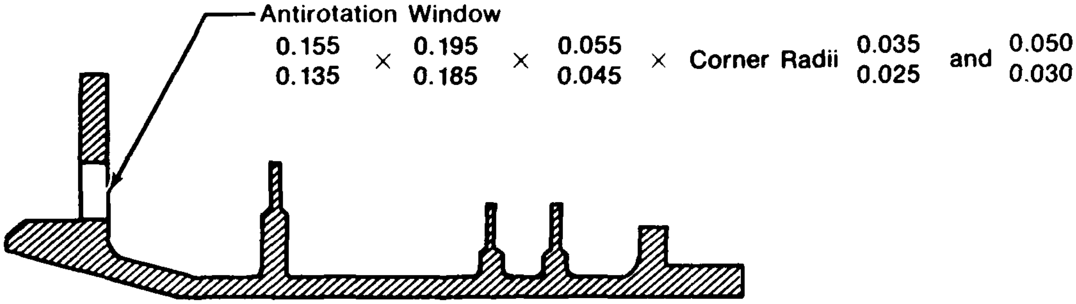


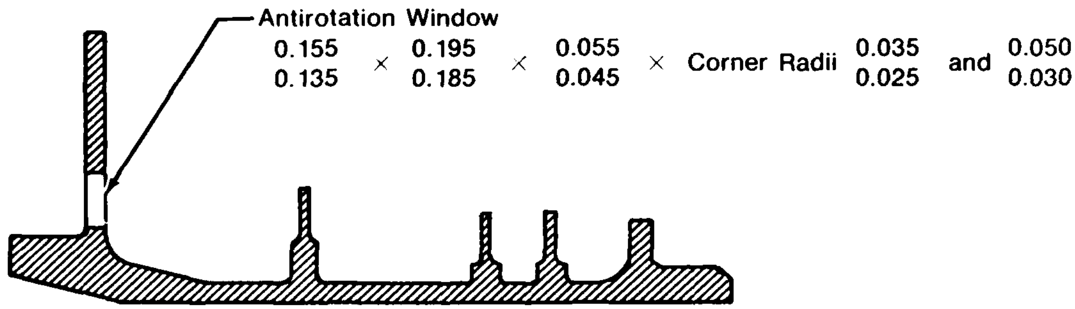
Figure H-14. 7-8 Compressor Spacer



Spacer OD 16.270 in. Material: Waspaloy
Spacer ID 15.240 in.
Height 1.760 in.

FD 223051

Figure H-15. 8-9 Compressor Spacer (P/N 4050978)



Spacer OD 16.330 in. Material: Waspaloy
Spacer ID 15.450 in.
Height 1.763 in.

FD 223052

Figure H-16. 9-10 Compressor Spacer (P/N 4050979)

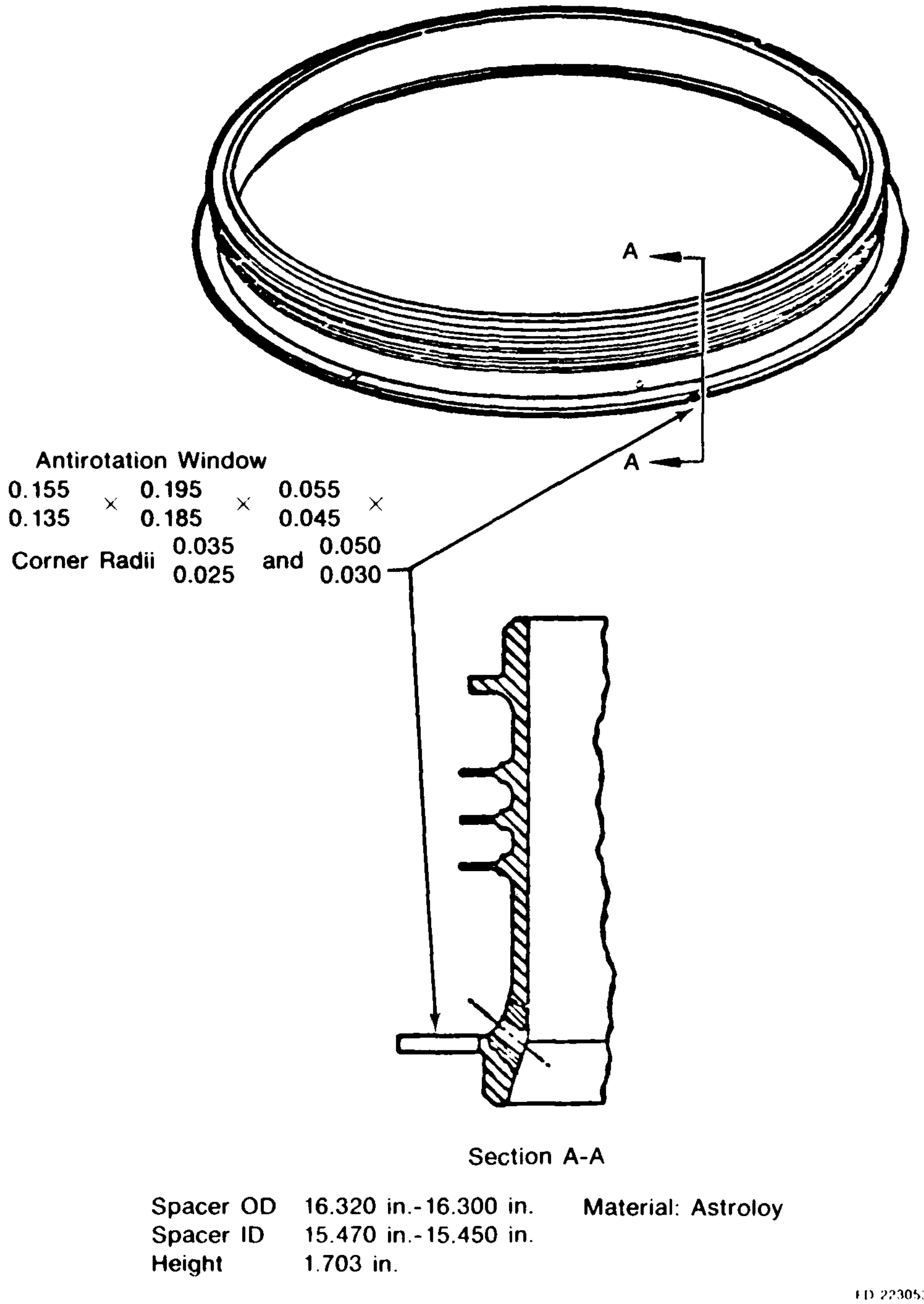
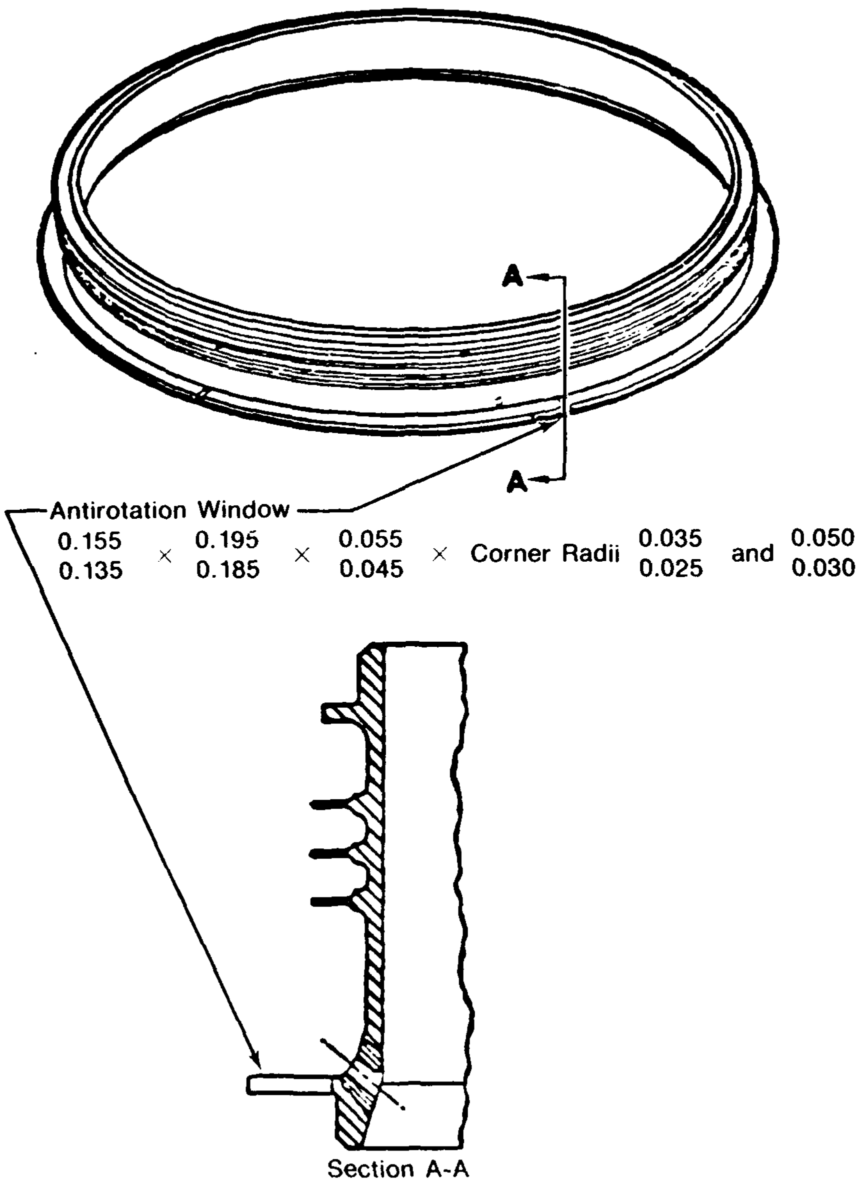


Figure H-17. 10-11 High Pressure Compressor Spacer (P/N 4043279)

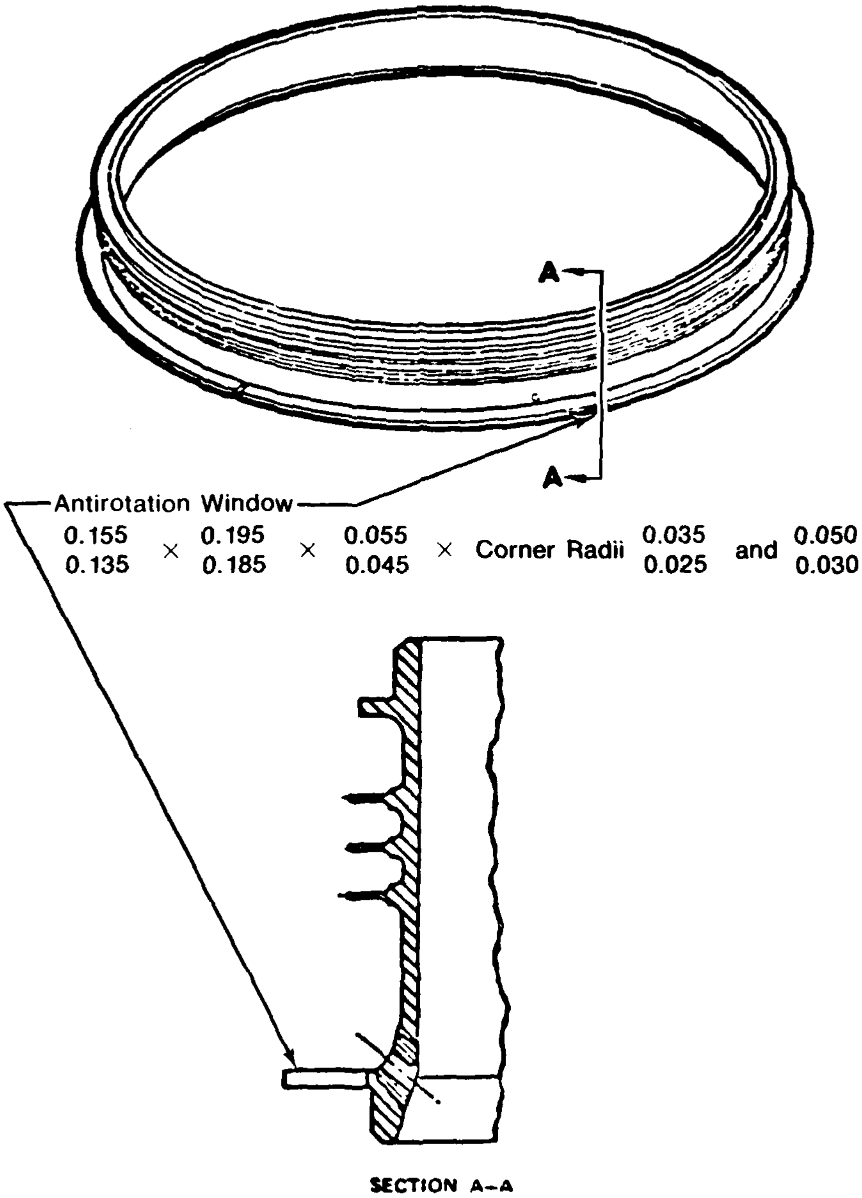


Spacer OD	16.330 in.-16.310 in.
Spacer ID	15.470 in.-15.450 in.
Height	1.705 in.

Material: Astroloy

FD 223054

Figure H-18. 11-12 High Pressure Compressor Spacer (P/N 4043280)

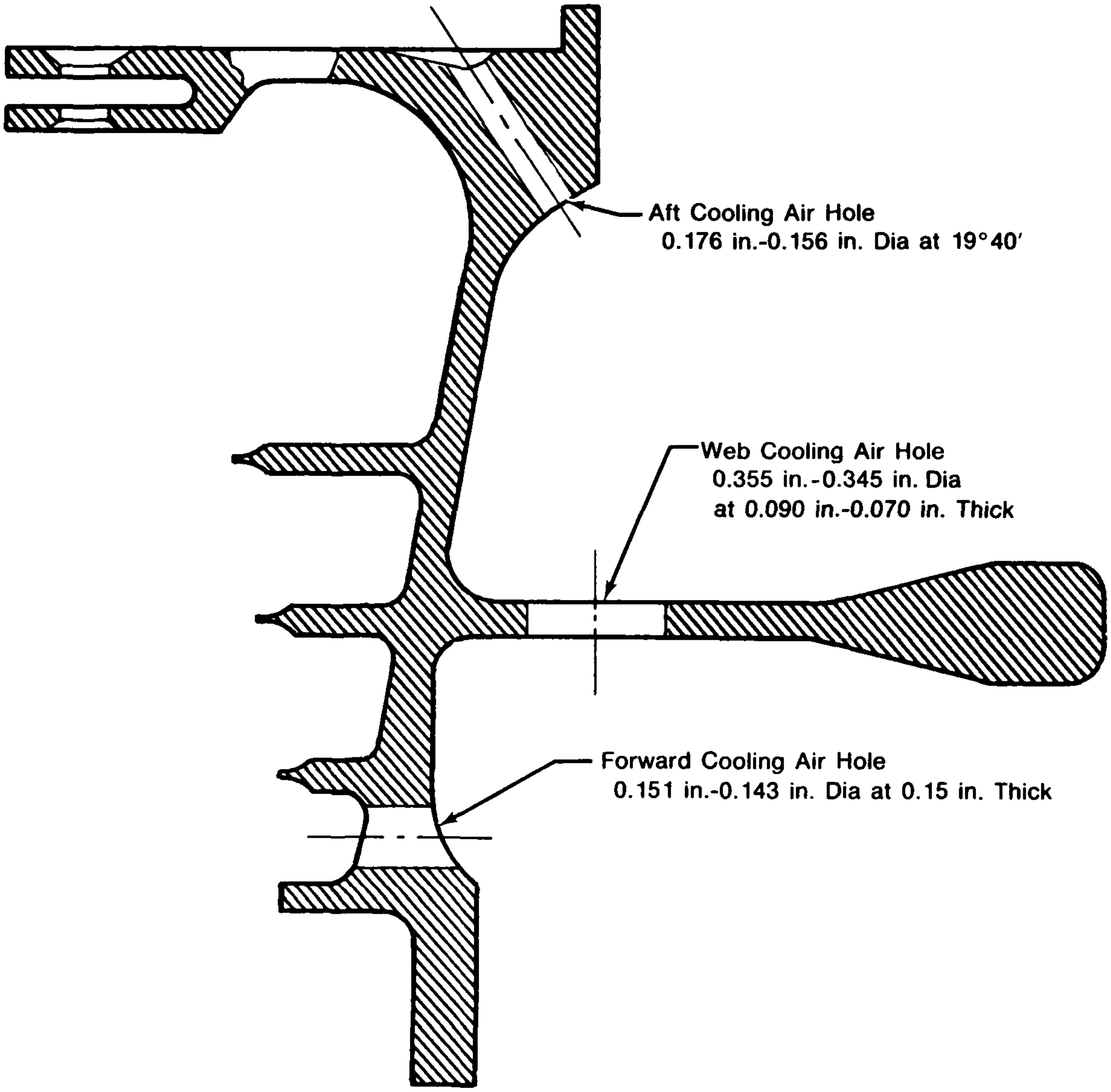


Spacer OD	16.330 in.-16.320 in.
Spacer ID	15.450 in.-15.470 in.
Height	1.612 in.

Material: Astroloy

FD 223055

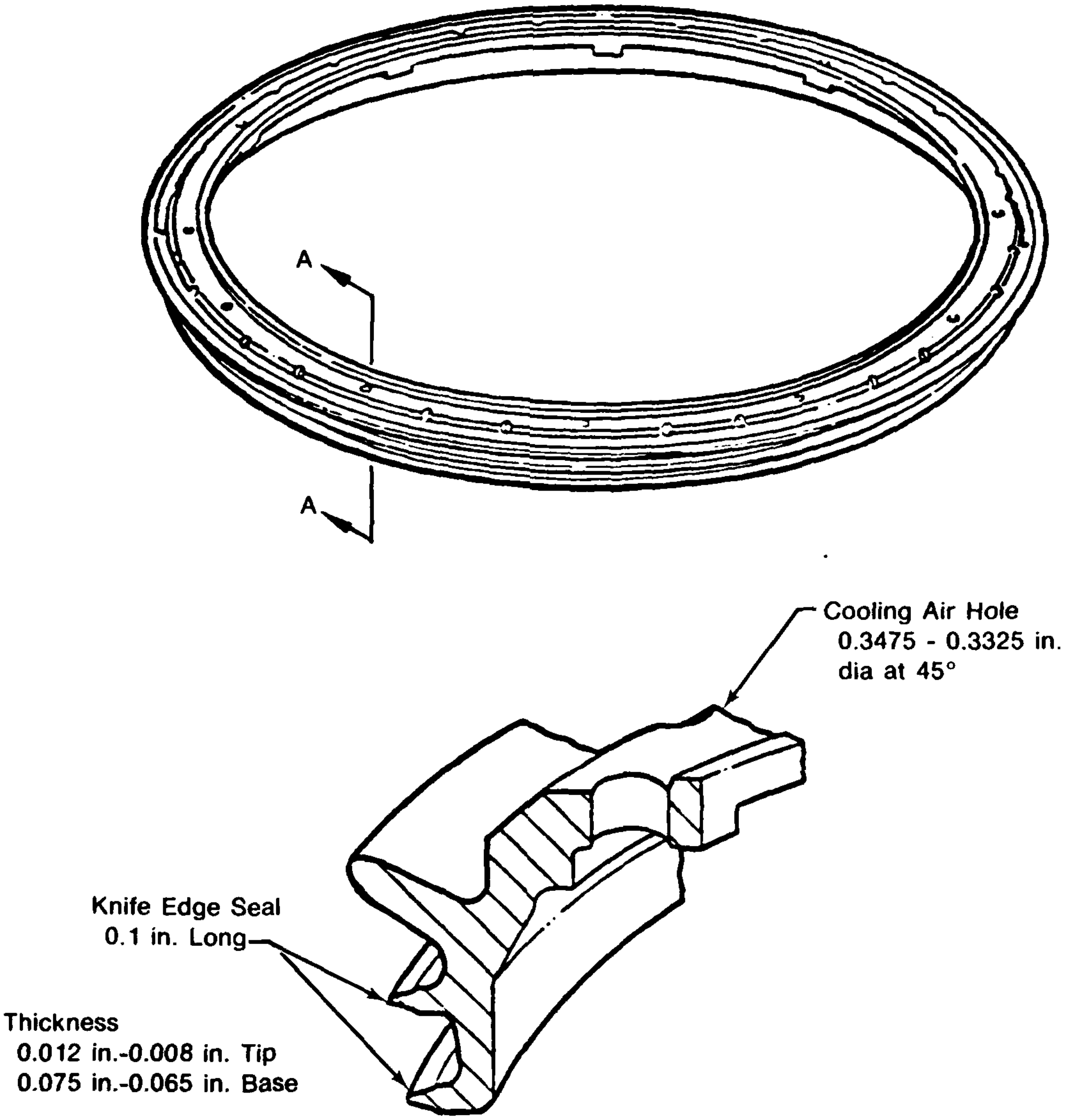
Figure H-19. 12-13 High Pressure Compressor Spacer (P/N 4041591)



Spacer OD 18.863 in. Material: GATORIZED® IN100
Spacer ID 13.395 in.
Height 2.745 in.

FD 223056

Figure H-20. High Pressure Turbine 1-2 Spacer (P/N 4042715)



Section A-A

Seal OD	17.735 in.-17.725 in.	Material: Astroloy
Seal ID	15.575 in.-15.565 in.	
Seal Height	1.250 in.	

FD 223057

Figure H-21. High Pressure Turbine Tangential on Board Injector Outside Diameter Seal (P/N 4036812)

2. APPLICABLE DOCUMENTS

The parts handling system will be designed, fabricated and installed in compliance with all applicable Military and Federal Specifications and Standards.

The conveyor system will be provided in accordance with Conveyor Equipment Manufacturers Association.

3. SYSTEM I

3.1 Major Component List

The parts handling subsystem is comprised of the following major components:

- Parts handling conveyor system consisting of:

1	Powered roller conveyor, 36 in. wide, from overhaul RFC to the inspection receiving station. This conveyor will include six right angle transfer mechanisms to effect transfer of boxes onto surge conveyors.
6	Gravity roller conveyors, 24 in. wide, to provide a buffer prior to receiving inspection.
1	Transfer powered roller conveyor, 36 in. wide.
1	Accumulation and delivery powered roller conveyor, 24 in. wide, with six right angle transfer mechanisms for the eddy current machines.
1	Accumulation powered roller conveyor, 36 in. wide.
1	Powered roller delivery conveyor, 24 in. wide, with three right angle transfer mechanisms for the ultrasonic machines.
1	Accumulation and delivery powered roller conveyor, 36 in. wide, which includes five right angle transfer mechanisms to effect the transfer of boxes onto surge conveyors for accepted parts.
1	Accumulation gravity roller conveyor, 24 in. wide, for rejected parts, including right angle transfer mechanism.
4	Gravity roller conveyors, 24 in. wide, to provide a buffer for accepted parts.
1	Powered roller conveyor, 36 in. wide, to transport pallets exiting the RFC area.
2	Powered roller conveyor sections, one 24 in. and the other 36 in. wide, to transport empty tote boxes back to overhaul.

3 Vertical lift sections to interconnect floor level and elevated conveyor.

1 Conveyor control system.

- 150 tote boxes, each with two permanent metal identification plates.
- One laser beam marking machine for inscribing "zero point" and part and serial numbers.
- One part number scanner at the induction station.
- 11 bar code scanner wands.
- One single rail hoist, 500 lb capacity, 12 ft span, with runways.
- Three dripstand and blowoff units at ultrasonic inspection.

3.2 Government Furnished Property List

The pallets or other suitable containers to transport the inspected modules to the storage/retrieval system of the repair facility will be furnished by the depot repair facility.

3.3 Item Definition

The parts handling subsystem will provide the means to stage and transport the parts from the existing overhaul operations throughout the RFC inspection process until they are placed back into storage subsequent to the inspection tests.

This system will consist of a series of powered and gravity roller conveyors with accumulating sections and right angle transfers. This system will also include the transport boxes that contain the parts.

3.3.1 Item Diagrams

Drawing I-1, Appendix I, provides a conceptual layout of the proposed parts handling subsystem. Figure H-22 contains a flow diagram which describes the sequence of part processing. Figure H-23 displays a conceptual transport container (tote box).

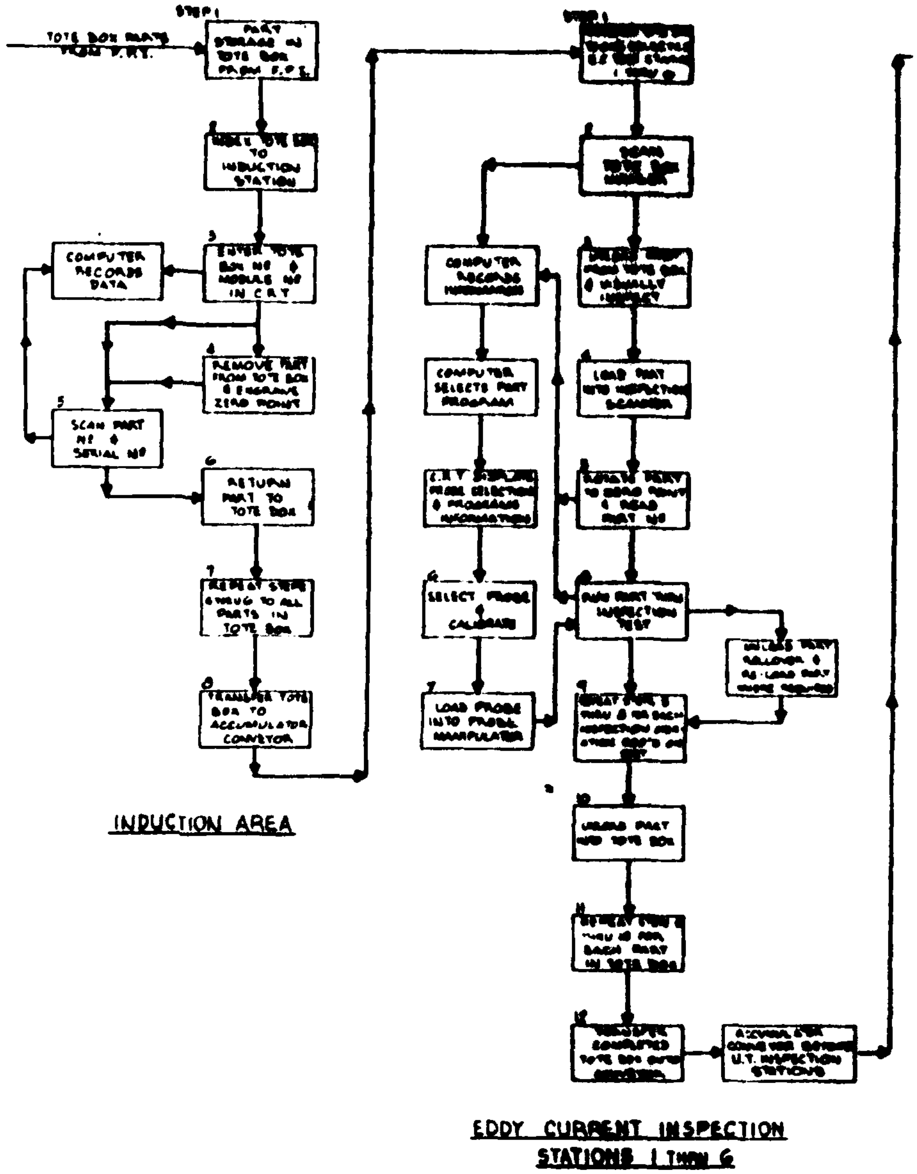
3.3.2 Interface Definition

All interfaces between conveyor and inspection equipment are manually performed, i.e., an operator removes each part from the tote box and places it in the inspection machines.

The conveyor control system will be directly interfaced with the inspection master computer system at the exit audit station. The computer system will automatically cause rejected modules to be routed to the reject spur.

The conveyor transporting tote boxes to and from the overhaul operations will be interfaced with the receiving conveyor for loaded tote boxes and the outgoing conveyor for empty tote boxes at the boundary of the RFC facility.

The conveyor transporting parts to the storage/retrieval system will be interfaced with the inspected parts removal conveyor at the boundary of the RFC facility.


TOTE BOX PARTS FROM P.R.T.
PART STORAGE IN TOTE BOX FROM F.P.I.
TO INDUCTION STATION
ENTER TOTE BOX Nº & MODULE Nº IN C.R.T.
COMPUTER RECORDS DATA
REMOVE PART FROM TOTE BOX & ENGRAVE ZERO POINT
SCAN PART Nº & SERIAL Nº
RETURN PART TO TOTE BOX
REPEAT STEPS 4 THRU 6 TO ALL PARTS IN TOTE BOX
TRANSFER TOTE BOX TO ACCUMULATOR CONVEYOR
INDUCTION AREA
COMPUTER RECORDS INFORMATION
COMPUTER SELECTS PART PROGRAM
C.R.T. DISPLAYS PROBE SELECTION & PROGRAMS INFORMATION
SELECT PROBE & CALIBRATE
LOAD PROBE INTO PROBE MANIPULATOR
LOAD PART INTO INSPECTION SCANNER
UNLOAD TOTE BOX
EDDY CURRENT INSPECTION STATIONS 1 THRU 6

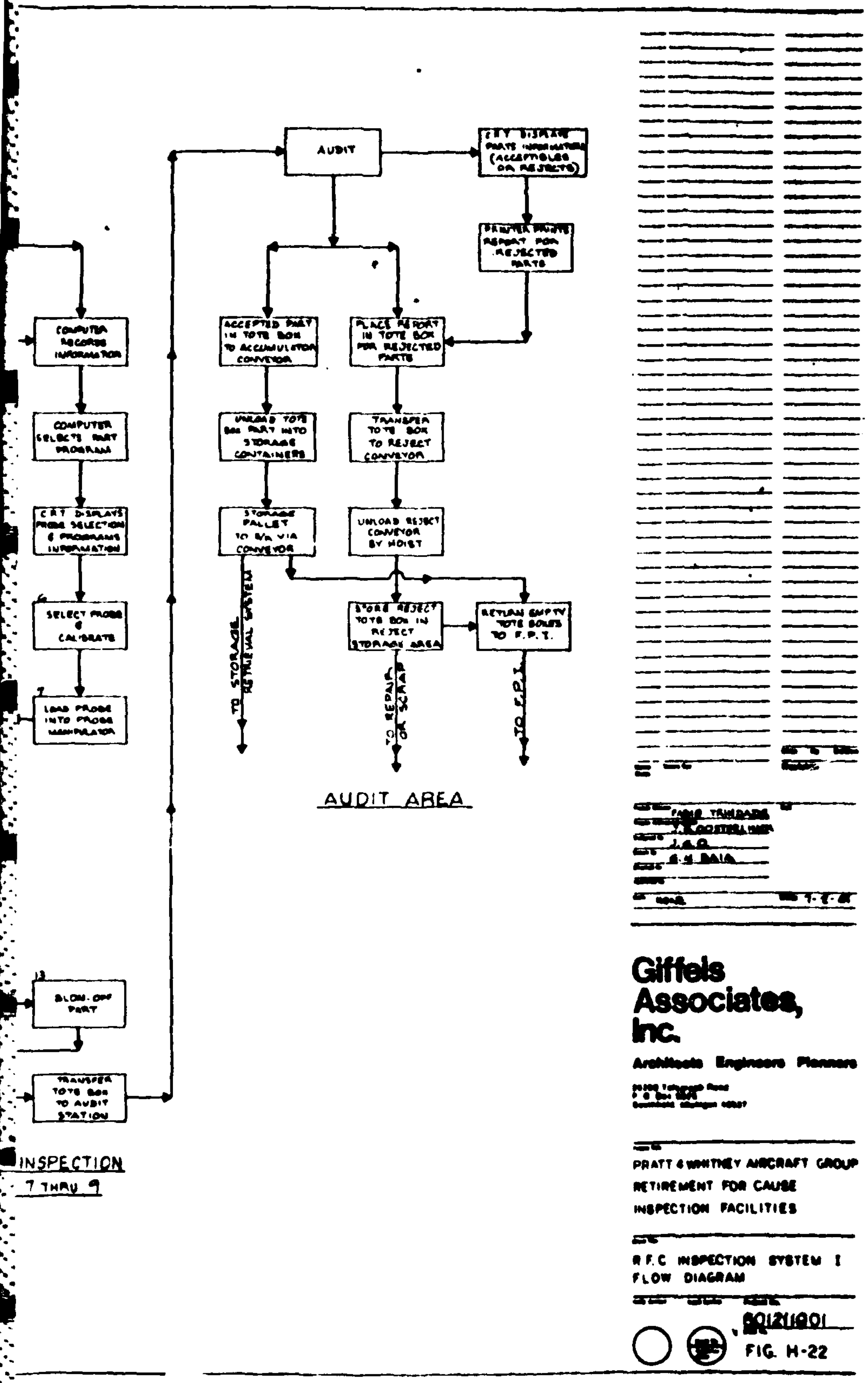
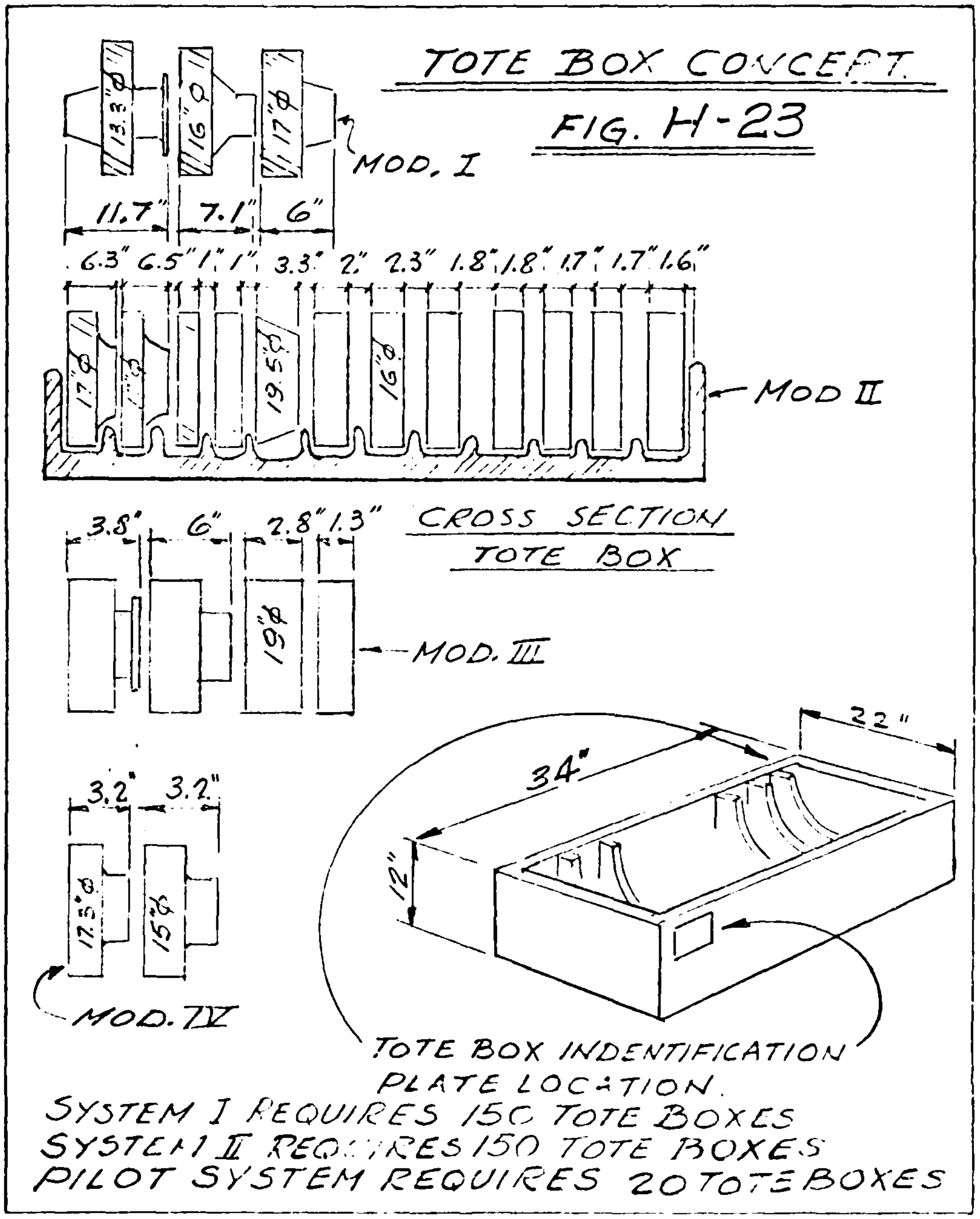


Figure H-22. RFC Inspection System I Flow Diagram

Giffels Associates, Inc.
Architects Engineers Planners

Made by: F. T. Chkd. by: Project No. 80121100I
Date: Date:
Title: Sheet 1 of 1



FD 217924

Figure H-23. Tote Box Concept

3.4 Performance

The parts handling subsystem will be capable of transporting the disks and spacers of the gas turbine engine at the required throughput.

The throughput is based on a processing rate of 100 engines per month. Each engine contains a total of 21 RFC disks or spacers grouped into four modules. The components of each module will remain together throughout the transportation and processing steps.

The throughput will be based on seven hours per day and 22 days per month for a total of 154 hr per month.

Modules will be supplied to the inspection stations on a first-in, first-out basis.

Parts handling and machine set-up times were estimated on a task by task basis. Refer to Table H-1. Because of the preliminary nature of this study, allowances were made for unforeseen tasks. These times, together with inspection and calibration times provided (Tables H-2 and H-3), established the total processing time required for each part.

Tables H-4 and H-5 provide the detail by part number and a summary of total processing hours required per month for the eddy current and ultrasonic stations.

The number of inspection stations required was determined by dividing the sum of monthly setup and machine times (Table H-5) by 154 hr per month:

$$\text{Eddy Current Machines:} \quad \frac{801.6 \text{ hr/mo}}{154 \text{ hr/mo}} = 5.2 \text{ machines}$$

$$\text{Ultrasonic Machines:} \quad \frac{301.1 \text{ hr/mo}}{154 \text{ hr/mo}} = 2.0 \text{ machines}$$

This assumes 100% efficiency on the part of the inspection equipment and average throughput rates for the system. Due to the sophistication of this equipment and the redundancy requirements, it is required that a minimum of six eddy current machines and three ultrasonic machines be provided.

The relationship between the time requirements for parts handling/machine setup and inspection is such that a machine operator can handle two machines.

Because the ultrasonic operation takes place under water and because not all parts require ultrasonic testing, these machines were grouped together and located downstream from the eddy current operations.

3.5 Design and Construction

The system will incorporate standard and interchangeable components. The design will be modular in nature for simplification and ease of installation.

TABLE H-1. PARTS HANDLING AND MACHINE SET-UP TIMES FOR SYSTEM I

		Time in Seconds Per		
		Module	Part	Operation
Standard Operations				
1.	Walk to load/unload station, scan bar code	60		
2.	Remove part from container		15	
3.	Visual inspection		20	
4.	Load part		25	
5.	Clamp part		45	
6.	Index part, read part number, load program		25	
7.	Read screen and select probe			25
8.	Load probe			30
9.	Calibrate (Calibrate Time – Table H-2)			Variable
10.	Start Test			5
	Run Test (Inspection Time – Table H-1)			Variable
11.	Walk to next machine			15
12.	Unclamp part		25	
13.	Remove part from machine		15	
14.	Place part in container		20	
15.	Release box from unload station and return	60		
		120	195	75
	Part Turnover			
16.	Unclamp		25	
17.	Remove part		15	
18.	Turnover		10	
19.	Reload part		25	
20.	Clamp		45	
21.	Index part		15	
			135	
	Ultrasonic Inspections			
22.	Blowoff		20	

TABLE H-2. NUMBER OF INSPECTIONS PER FEATURE

Part	*Scallops 10 sec*	*Boltholes 15 sec*	*Web 18 min*	*Bore 15 min*	*Rim Slot Corner 10 sec*	*Drain Slot 10 sec*	*Angle Cooling 15 sec*	*Axial Cooling 15 sec*	*Rad Hole 15 sec*	*Rotation Slot 10 sec*	*Knife Edge 1 min*
1F	40	24	X	X	48	6					
2F	40	24	X	X	64						
3F	40	24	X	X	48						
4C	40										
7C		28									
8C		28		X	96						
12C					96						
1T		20		X			60	30			
2T		20					60/20				
3T			X	X					30		
4T			X	X							
2/3 CPS					6					6	
6/7 CPS										6	
7/8 CPS										6	
8/9 CPS										6	
9/10 CPS										6	
10/11 CPS										6	
11/12 CPS										6	
12/13 CPS										6	
1/2 TS							60	10	30		
TOBI							30			2	

TABLE H-3. INSPECTION TIMES

Operation	*Time*	*Calibration Time*
Scallops	10 sec	20 sec
Holes	15 sec	30 sec
Web Eddy Current	4½ min per side	15 sec
Web Ultrasonics	4½ min per side	2 min
Bore Eddy Current	7½ min total	15 sec
Bore Ultrasonics	7½ min total	2 min
Drain Slot	10 sec	20 sec
Rotation Slot	10 sec	20 sec
Knife Edge	1 min	20 sec
Rim Slot Corners	10 sec	20 sec

TABLE H-4A. PROCESS TIME REQUIREMENTS IN SECONDS (UNLESS NOTED) FOR SYSTEM I — MODULE I

Part ID	Operations	Eddy Current Test Inspection	Calibration	Handl/ Setup	Total Time	Hours mo	Ultrasonic Test Inspection	Calibration	Handl/ Setup	Total Time	Hours mo
1F	Load and Unload			195	195				195	195	
	Scalllops	400	20	75	495						
	Rim Slots	480	20	75	575						
	Web Test Side 1	270	15	75	360		270	120	75	465	
	Web Test Side 2	270	15	210	495		270	120	230	620	
	Boltholes	360	30	75	465						
	Bore	450	15	75	540		450	120	95	665	
	Drain Slots	60	20	75	155						
	Total	2,290	135	855	3,280	91.1	990	360	595	1,945	54.0
2F	Load and Unload			195	195				195	195	
	Scallops	400	20	75	495						
	Rim Slots	640	20	75	735						
	Web Test	270	15	75	360		270	120	75	465	
	Web Test	270	15	210	495		270	120	230	620	
	Boltholes	360	30	75	465						
	Bore	450	15	75	540		450	120	95	664	
	Total	2,390	115	780	3,285	91.3	990	360	595	1,945	54.0
3F	Load and Unload			195	195				195	195	
	Scallops	400	20	75	495						
	Rim Slots	480	20	75	575						
	Bore	450	15	75	540		450	120	95	665	
	Boltholes	360	30	75	465				95	665	
	Total	1,690	85	495	2,270	63.1	450	120	290	860	23.9
	Move tote box			120	120	3.3			120	120	3.3
	Total, Module I	6,370	335	2,250	8,955	248.8	2,430	840	1,600	4,870	135.3

TABLE H-4B. PROCESS TIME REQUIREMENTS IN SECONDS (UNLESS NOTED FOR SYSTEM I — MODULE II

Part ID	Operations	Eddy Current Test Inspection	Calibration	Handl/ Setup	Total Time	Hours mo	Ultrasonic Test Inspection	Calibration	Handl/ Setup	Total Time	Hours mo
4C	Load and Unload			195	195						
	Scallops	400	20	75	495						
	Total	400	20	270	690	19.2					
7C	Load and Unload			195	195						
	Boltholes	420	30	75	525						
	Total	420	30	270	720	20.0					
8C	Load and Unload			195	195				195	195	
	Rim Slot	960	20	75	1,055						
	Boltholes	420	30	75	525						
	Bore	450	15	75	540		450	120	95	665	
	Total	1,830	65	420	2,315	64.3	45	120	290	860	23.9
12C	Load and Unload			195	195						
	Rim Slot	960	20	75	1,055						
	Total	960	20	270	1,250	34.7					
2-3 CPS	Load and Unload			195	195						
	Rim Slot Corner	60	20	75	155						
	Rotation Slot	60	20	75	155						
	Total	120	40	345	505	14.0					

TABLE H-4B. PROCESS TIME REQUIREMENTS IN SECONDS (UNLESS NOTED FOR SYSTEM I — MODEL II (Continued)

		Eddy Current Test					Ultrasonic Test				
Part ID	Operations	Inspection	Calibration	Handl/ Setup	Total Time	Hours mo	Inspection	Calibration	Handl/ Setup	Total Time	Hours mo
6/7	Load and Unload			195	195						
CPS	Rotation Slot	60	20	75	155						
	Total	60	20	270	350	9.7					
7/8	Load and Unload			195	195						
CPS	Rotation Slot	60	20	75	155						
	Total	60	20	270	350	9.7					
8/9	Load and Unload			195	195						
CPS	Rotation Slot	60	20	75	155						
	Total	60	20	270	350	9.7					
9/10	Load and Unload			195	195						
CPS	Rotation Slot	60	20	75	155						
	Total	60	20	270	350	9.7					
10/11	Load and Unload			195	195						
CPS	Rotation Slot	60	20	75	155						
	Total	60	20	270	350	9.7					
11/12	Load and Unload			195	195						
CPS	Rotation Slot	60	20	75	155						
	Total	60	20	270	350	9.7					
12/13	Load and Unload			195	195						
CPS	Rotation Slot	360	20	75	455						
	Total	360	20	270	650	18.1					
	Move tote box			120	120	3.3			120	120	3.3
	Total, Module II	4,450	315	3,585	8,350	231.8	450	120	410	980	27.2

TABLE H-4C. PROCESS TIME REQUIREMENTS IN SECONDS (UNLESS NOTED) FOR SYSTEM I — MODULE III

		Eddy Current Test					Ultrasonic Test				
Part ID	Operations	Inspection	Calibration	Handl/ Setup	Total Time	Hours mo	Inspection	Calibration	Handl/ Setup	Total Time	Hours mo
1T	Load and Unload			195	195						
	Boltholes	300	30	75	405						
	Angle Cooling Holes	900	30	75	1,005						
	Axial Cooling Holes	450	30	75	555						
	Bore	450	15	75	540						
	Total	2,100	105	495	2,700	75.0					
2T	Load and Unload			195	195				195	195	
	Boltholes	300	30	75	405		450	120	95	665	
	Angle Cooling Holes	1,200	30	75	1,305						
	Total	1,500	60	345	1,905	52.9	450	120	290	860	23.9
1/2T	Load and Unload			195	195						
	Angle Cooling Holes	900	30	75	1,005						
	Axial Cooling Holes	150	30	75	255						
	Radial Holes	450	30	75	555						
	Total	1,500	90	420	2,010	55.8					
1OBI	Load and Unload			195	195						
	Angle Cooling Holes	450	30	75	555						
	Knife Edge	120	20	75	215						
	Total	570	50	345	965	26.8					
	Move tote box			120	120	3.3			120	120	3.3
	Total, Module III			1,725	7,700	213.8	450	120	410	980	27.2

TABLE H-4D. PROCESS TIME REQUIREMENTS IN SECONDS (UNLESS NOTED) FOR SYSTEM I — MODULE IV

		Eddy Current Test					*Ultrasonic Test*				
Part ID	*Operations*	*Inspection*	*Calibration*	*Handl/ Setup*	*Total Time*	*Hours mo*	*Inspection*	*Calibration*	*Handl/ Setup*	*Total Time*	*Hours mo*
3T	Load and Unload			195	195				195	195	
	Radial Holes	450	30	75	555						
	Bore	450	15	75	540		450	120	95	665	
	Web 1	270	15	75	360		270	120	75	465	
	Web 2	270	15	210	495		270	120	230	620	
	Total	1,440	75	630	2,145	59.6	990	360	595	1,945	54.0
4T	Load and Unload			195	195				195	195	
	Bore	450	15	75	540		450	120	95	665	
	Web 1	270	15	75	360		270	120	75	465	
	Web 2	270	15	210	495		270	120	230	620	
	Total	990	45	555	1,590	44.2	990	360	595	1,945	52.9
	Move tote box:			120	120	3.3			120	120	3.3
	Total, Module IV:	2,430	120	1,305	3,855	107.1	1,980	720	1,310	4,010	111.1

TABLE H-5. SUMMARY OF PROCESSING TIME REQUIREMENTS BY MODULE NUMBER — TIME IN HOURS PER MONTH FOR SYSTEM I

	Eddy Current			*Ultrasonic*		
	Handling/ Setup	*Calibration/ Inspection*	*Total*	*Handling/ Setup*	*Calibration/ Inspection*	*Total*
Module No. 1	71.8	176.9	248.7	67.8	67.5	135.3
No. 2	108.3	123.6	231.9	14.7	12.5	27.2
No. 3	56.4	157.5	213.9	14.7	12.5	27.2
No. 4	39.6	67.5	107.1	56.4	55.0	111.4
Total Hours/ Month:	276.1	525.5	801.6	153.6	147.5	301.1
Machines Required at 100% Efficiency:			5.2			2.0
Recommended Number of Machines:			6			3

3.6 Physical Characteristics

There are no special weight limitations that apply to the parts handling system. Loading imposed by the equipment will be in conformance with the requirements for light industrial facilities.

The system will be designed to conform to the specified clear height of 18 ft for the RFC facility.

The conveyor system will be built for conventional industrial use and will be permanently installed.

The equipment will incorporate all necessary safety features in order to protect personnel during installation, operation and maintenance.

3.7 Reliability

The system will be designed with sufficient ruggedness and capacity and with the application of standard and interchangeable components in order to achieve a high level of reliability.

3.8 Maintainability

The conveyor control system will have self-test diagnostics to assist in maintenance activities. All major components will be interchangeable insofar as practical. All conveyor drives, actuators and other components requiring frequent service will be located for easy access.

3.9 Environmental Conditions

The parts handling system will be designed to operate in a normal maintenance facility environment.

3.10 Major Components Characteristics

3.10.1 Parts Handling Conveyor System

1. Power roller conveyor to transport modules in tote boxes from the FPI area. The conveyor will be provided with six stops and right angle transfer mechanisms to divert the boxes onto the surge conveyors. The stops and transfer mechanisms will be programmed to effect the transfer sequentially from one accumulation to the next. The conveyor has two levels (floor and elevated) which will be connected with a vertical lift.

2. Gravity roller conveyors for accumulation prior to induction station. A release-restrain mechanism will be provided at the exit end of each conveyor so that one box is released at a time onto the transfer conveyor. The release mechanism will be actuated remotely by the operator at the induction station. The conveyor will be designed to maintain the box flow through the conveyor without excessive acceleration but with assurance of movement.

3. Power roller transfer conveyor to deliver boxes to the induction station. The conveyor will be actuated on demand by the operator at the induction station. Upon completion of the activities at the induction station, the box will be transported to the end of the conveyor and a right angle transfer mechanism will deliver the box to the accumulation conveyor prior to the inspection stations.

4. Power roller conveyor for accumulation and delivery of tote boxes to the eddy current inspection stations. The portion of the conveyor up to the first transfer mechanism will be used for accumulation of tote boxes. A stop with a release-restrain mechanism will be provided to allow only one box to move out at a time.

   The remainder of the conveyor will supply and remove tote boxes from the eddy current inspection stations.

At the completion of an inspection, the station operator will actuate a switch which will activate the right angle transfer and the conveyor to remove the box. The switch will also release the stop at the accumulating conveyor and another box will be conveyed to the same inspection station by means of the delivery conveyor and right angle transfer mechanism.

When a tote box reaches the end of the delivery conveyor, it will actuate a switch to effect the transfer onto the accumulator conveyor prior to the ultrasonic inspection stations.

5. Power accumulation conveyor will stop and a release-restrain mechanism will be provided to allow only one box to move out at a time. The release mechanism will be activated by switches located, and actuated by operators, at the ultrasonic inspection stations.

6. Power roller conveyor for delivery and removal of tote boxes for the ultrasonic inspection stations. This conveyor will be provided with the same features as specified in item 4, above.

7. Power roller conveyor for accumulation prior to the audit station and delivery of tote boxes to either the rejected or accepted parts accumulation conveyors.

   On completion of the auditing, the operator will activate a switch to release the box to the transfer mechanism. The conveyor control system will be interfaced with the inspection master control system. Upon direction from the computer system, the computer control will set up a stop and activate the right angle transfer mechanism to divert the box to the reject spur, or allow the box to travel to the gravity buffer roller conveyor for accepted parts. The conveyor will be provided with four stops and right angle transfer mechanisms to divert the boxes onto the surge conveyor. The stop and transfer mechanisms will be automatic and programmed to effect the transfer sequentially from one spur to the next.

8. Gravity roller conveyor for tote boxes with rejected parts.

9. Gravity roller conveyors for tote boxes with accepted parts.

10. Power roller conveyor to transport loaded container or pallet with parts destined to the storage/retrieval system. The conveyor will operate intermittently at the command of the operator unloading the system. The conveyor has two levels (floor and elevated) which will be connected with a vertical lift.

11. Power roller conveyor with a right angle transfer to transport empty tote boxes to the FPI area. The conveyor has two levels (floor and elevated) which will be connected with a vertical lift. The conveyor will operate intermittently at the command of the operator unloading the system.

12. Vertical lifts to connect floor mounted conveyors to elevated conveyors. These lifts will be designed to automatically receive, elevate and discharge the loads between the two levels of the conveyors.

13. Conveyor control system will be designed to include all the functional requirements described in this section and as required to make a complete and integrated system.

3.10.2 Tote boxes 34 in. long, 22 in. wide and 12 in. high for transport of modules throughout the system. The boxes will have dividers for separation of parts. The boxes will be made of high impact plastic or fiberglass. Each box will contain two metal plates permanently attached at opposite sides and engraved with a permanent and unique bar code and its numerical equivalent. The bottom of the boxes will be flat and suitable for transportation by roller conveyor.

3.10.3 High speed laser beam marking machine for inscribing the marking of the "zero point" on the surface(s) of the parts. The machine will also be used to inscribe the part number and serial number if these are not present or not suitable for machine reading.

The machine will be provided with a fixture to properly secure and position the part to be marked. The markings will be engraved on annuli surfaces.

All alpha-numeric characters will be provided and in sizes suitable to the surface of the part which will be designated for the engraving.

The machine will be provided with a CRT for data input and microprocessor to automatically control the functions of the engraving.

3.10.4 Part number scanner capable of reading alpha-numeric characters inscribed on the disks or spacers. Information read will be transmitted to the inspection master computer system.

3.10.5 Bar code reader wand to optically scan and transmit bar code symbol data to the inspection master computer system.

3.10.6 Single girder monorail hoist ¼-ton capacity, motorized, 12 ft span, underhung, pendant floor operated, with 25 ft long runway.

3.10.7 Drip stand for ultrasonic inspection station. Stand will be built of corrosion-proof material and be of sufficient height to allow the dripping to flow back to the tank. The stand will be supplied with a compressed air blowoff gun.

3.11 Summary of Operation

The sequence of operations for the system is illustrated in the flow diagram Figure H-22. The equipment configuration is illustrated in Drawing I-1.

Parts will come from the overhaul area via a 24 in. powered roller conveyor. The parts will be transported in tote boxes 34 in. long by 22 in. wide by 12 in. high. Each box will carry parts for a complete module. The parts will be stacked and separated by dividers. Refer to Figure H-23.

Each tote box will have a metal plate permanently attached to the side. This plate will contain a unique number and the bar code representation of this number for each box. This number will be used to inform the computer of the location and status of each module as it is processed.

3.11.1 Induction Area

At the induction area, the modules will be transferred onto gravity roller conveyors for buffer storage. These conveyors will have capacity to store a three-day buffer.

The induction operator wiil release the boxes from the buffer area as necessary in a first-in first-out order at the pace required by the inspection process. Upon release, a box will be automatically transported to a position in front of the receiving operator and stop. The operator will first scan the bar code on the side of the tote box with a hand-held scanner and key in the module number (1 through 4) on his CRT terminal. He will then remove each part from the box, one at a time, and verify that the "zero" reference point marking exists. This marking will be required on all parts so that the point where the inspection starts becomes fixed. If the "zero" reference point is not present, the operator will load the part into an engraving machine to have it properly marked.

Next, the operator will read the part number and serial number with an instrument similar to the reader located at each inspection station, to ensure readability. If the part number and/or serial number are not machine readable, he must re-inscribe the number. This will be accomplished by means of a machine located at his station.

When the induction operator has finished these tasks, he releases the tote box which is then conveyed via a right angle transfer onto the delivery conveyor. The first portion of the delivery conveyor acts as holding storage for the eddy current inspection machines.

3.11.2 Inspection Stations

A load/unload station is provided adjacent to the delivery conveyor at each inspection station. When an inspection operator has completed all work on a module, he actuates a switch which activates the transfer of the box onto the delivery conveyor where it will be conveyed to the ultrasonic inspection operation. When the tote box moves off the load station a message is sent to the conveyor control system to release the next tote box from the holding storage and convey it to this station. Upon arrival at the station, a stop will be raised and a transfer mechanism will move the tote box to the load/unload station. Since an operator will usually be working on two inspection machines at the same time, this conveyance method should not induce idle time.

3.11.3 Eddy Current Inspection

At the inspection station the operator scans the bar code, which is located on the plate attached to the tote box, with a wand. This information is then transmitted automatically to the inspection master computer system and the proper inspection program is downloaded to the inspection station computer system. This system then begins to prompt the inspection operator through the required steps for each part number within the module.

For some parts, multiple tests will be required. Also, some parts require tests on both sides of the parts. The inspection steps are outlined briefly in Figure H-22.

As shown in Table H-4, for all parts, the handling and set-up time is less than or equal to the inspection (machine) time. Therefore one inspection operator has sufficient time to operate two machines. In order to minimize the risk of mixing up the parts, and reduce the complexity of the computer control system, it is necessary that if an operator is operating two machines, each machine will inspect a separate and complete module, instead of bringing a module in and placing the first part in one machine, the second part in the second machine, and alternating machines until all parts have been processed. The reliability of the overall system is increased since each machine station can be viewed as an independent unit.

Once the module has been released from one of the six eddy current inspection stations, it will be conveyed until stopped at an accumulation section of the conveyor prior to the ultrasonic inspection stations.

3.11.4 Ultrasonic Inspection

The ultrasonic inspections stations will operate in a similar manner as was just described for the eddy current stations. The exception is that these tests will be performed under water in a tank. Once all inspections for each part are complete, the part will be set on a stand to drain off the water and will be blown dry with compressed air prior to being placed back in the tote box.

Only some of the parts within each module require ultrasonic inspection. Therefore, once the operator has identified the module to the computer by means of the scanner wand, the computer system will prompt the operator on which part(s) to load. The part number reader associated with the inspection machine will verify that the proper part has been loaded before allowing the test to continue.

Once the ultrasonic inspections for the module are finished, the operator actuates a switch which activates the transfer of the box onto the conveyor and the box is conveyed to an accumulating section of conveyor located prior to the final audit and inspection station.

3.11.5 Audit Station

At this station, the operator scans the bar-code on the plate attached to the tote box. If any of the inspections for any of the parts in the module indicate that that part has flaws a report will be automatically printed on a line printer and placed in the tote box. The conveyor will then automatically transfer this box to the reject spur. All other (acceptable) boxes will be transferred to the accumulation spurs.

At the reject spur, an overhead hoist will be furnished to remove the tote boxes from the conveyor and stage them for final disposition.

The acceptable parts accumulation spurs consist of gravity roll conveyors. At the end of the gravity roll conveyors an operator will unload the parts and place them in storage containers suitable for the storage/retrieval system available at the depot engine maintenance center. The operator will load only one module per storage container in order to maintain the components of each module together. The storage containers will then be conveyed to the storage area. The empty tote boxes will be conveyed back to the FPI area.

4. SYSTEM II

4.1 Major Component List

The parts handling subsystem is comprised of the following major components:

- Parts handling conveyor system consisting of:

  1 Powered roller conveyor, 24 in. wide, from overhaul area to the induction station. This conveyor will include seven right angle transfer mechanisms to effect transfer of boxes onto surge conveyors.

  7 Gravity roller conveyors, 36 in. wide, to provide a buffer prior to induction station.

  1 Transfer powered roller conveyor, 24 in. wide, to stage boxes for the induction station and to return empty boxes to the overhaul area.

  1 Power and free conveyor complete with carriers, stops, scanners, switches, spurs, accumulating lanes and secondary supporting structure.

  1 Gravity roller conveyor, 24" wide, for accumulation of rejected parts.

  1 Powered roller conveyor, 36" wide to transport pallets exiting the RFC area.

  1 Vertical lift sections to connect floor level and elevated conveyors.

  1 Conveyor control system.

  18 Automatic industrial robots for loading and unloading parts at the inspection stations.

  13 Parts rollover devices.

- 22 conveyor carrier scanners.
- Three dripstand and blowoff units at ultrasonic inspection.
- One laser beam marking machine for inscribing the "zero" point and part/serial number
- One part number scanner at the induction station.
- One single rail hoist, 500 lb capacity, 25 ft span, with runways.
- 100 tote boxes to transport modules from the overhaul.

4.2 Government Furnished Property List

The pallets or other suitable containers to transport the inspected modules to the storage/retrieval system of the repair facility will be furnished by the depot repair facility.

4.3 Item Definition

The parts handling subsystem will provide the means to stage and transport the parts from the fluorescent penetrant and dimensional inspection operations throughout the RFC inspection process until they are placed back into storage subsequent to the inspection tests.

This system will consist of a series of powered and gravity roller conveyors and a power and free conveyor.

This system will also include the transport boxes that contain the parts.

4.3.1 Item Diagrams

Drawing I-2 provides a conceptual layout of the proposed parts handling subsystem. Figure H-24 contains a flow diagram which describes the sequence of part processing. Figure H-23 displays a conceptual transport container (tote box).

4.3.2 Interface Definition

All interface between conveyor and inspection machines will be performed by industrial robots. The robots will be interfaced with the conveyor control system.

The conveyor control system will be interfaced with the inspection master computer system. The computer system will communicate with the conveyor control system as necessary to control the routing of the parts through the system.

The conveyor transporting tote boxes to and from the overhaul operations will be interfaced with the receiving conveyor for loaded tote boxes at the boundary of the RFC facility.

The conveyor transporting parts to the storage/retrieval system will be interfaced with the inspected parts removal conveyor at the boundary of the RFC facility.

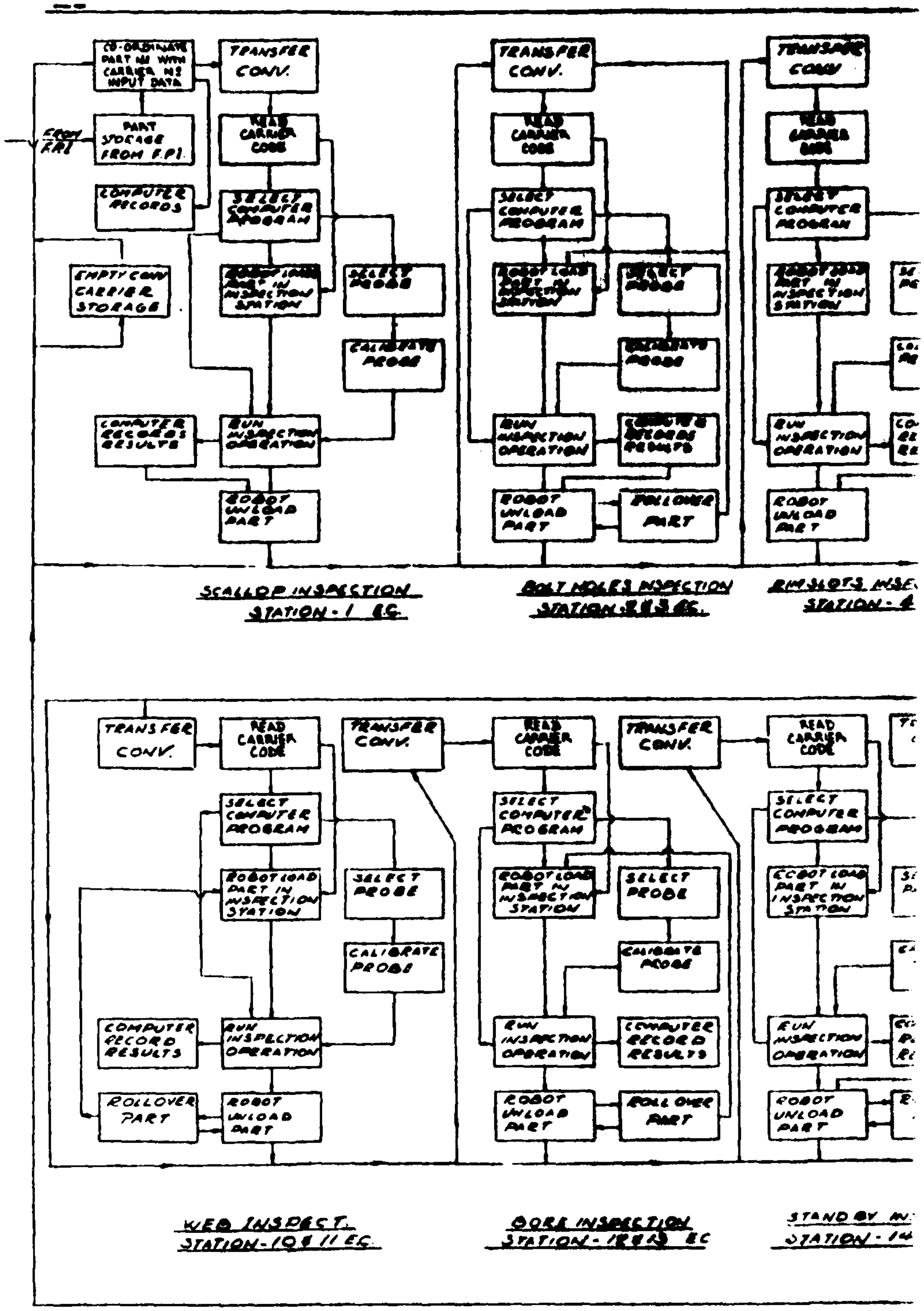
4.4 Performance

The part handling subsystem will be capable of transporting the disks and spacers of the gas turbine engine at the required throughput.

The throughput is based on a processing rate of 200 engines per month. Each engine contains a total of 21 RFC disks or spacers grouped into 4 modules. The components of each module will be regrouped at the completion of the transportation and processing steps.

The throughput will be based on seven hours per day and 22 days per month for a total of 154 hours per month.

Modules will be supplied to the induction station on a first-in, first-out basis.



CO-ORDINATE PART NO WITH CARRIER NO INPUT DATA
TRANSFER CONV.
FROM FPI
PART STORAGE FROM F.P.I.
READ CARRIER CODE
COMPUTER RECORDS
SELECT COMPUTER PROGRAM
EMPTY CONV CARRIER STORAGE
ROBOT LOAD PART IN INSPECTION STATION
SELECT PROBE
CALIBRATE PROBE
COMPUTER RECORDS RESULTS
RUN INSPECTION OPERATION
ROBOT UNLOAD PART
ROLLOVER PART
SCALLOP INSPECTION STATION - 1 EC
BOLT HOLES INSPECTION STATION - 2 & 3 EC
STATION - 4
TRANSFER CONV.
READ CARRIER CODE
SELECT COMPUTER PROGRAM
ROBOT LOAD PART IN INSPECTION STATION
SELECT PROBE
CALIBRATE PROBE
COMPUTER RECORD RESULTS
RUN INSPECTION OPERATION
ROLLOVER PART
ROBOT UNLOAD PART
WEB INSPECT. STATION - 10 & 11 EC.
BORE INSPECTION STATION - 12 & 13 EC
STAND BY

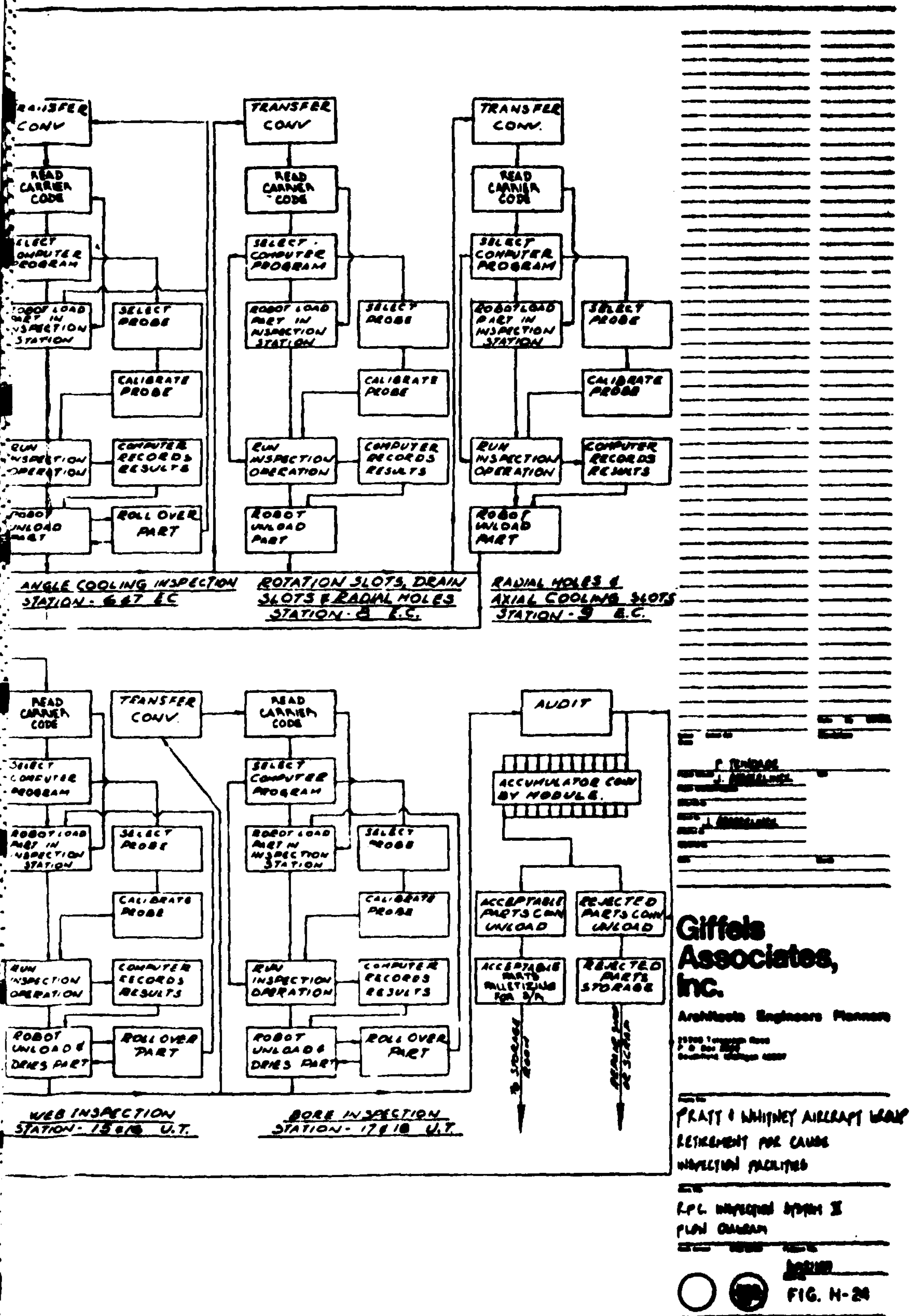


Figure H-24. RFC Inspection System II Flow Diagram

The higher throughput and higher efficiency to be gained by more automation at the processing level of 200 engines per month became the basis for assigning a dedicated machine for each type of inspection wherever possible, a multi-routing with accumulation parts handling system, and automatic industrial robots for loading and unloading parts at the inspection stations.

Parts handling and machine set-up times were estimated on a task by task basis. Refer to Table H-6. Because of the preliminary nature of this study, allowances were made for unforeseen tasks. These times, together with inspection and calibration times provided (Tables H-2 and H-3), established the total processing time required for each part.

Tables H-7 and H-8 provide the detail by operation and a summary of total processing hours required per month for the eddy current and ultrasonic stations.

TABLE H-6. PARTS HANDLING AND MACHINE SETUP TIMES FOR SYSTEM II

		Seconds
	Standard Operations	
1.	Index carrier to unload position	40
2.	Lock carrier in position	10
3.	Unload part from carrier	10
4.	Load part into inspection fixture	20
5.	Lock parts fixture	5
6.	Position part to zero point	5
7.	Calibrate (see table H-2) Run test (see table H-1)	Variable Variable
8.	Unlock fixture and retract probe holder	5
9.	Remove part from fixture	20
10.	Return part to carrier	10
11.	Unlock carrier	5
		130
	Part Turnover	
12.	Load part into rollover fixture	20
13.	Clamp part	5
14.	Rollover	5
15.	Unload and transfer to machine	20
16.	Restore part to initial orientation (repeat steps 12-15)	50
		100
	Ultrasonic Inspection	
17.	Blowoff	30

TABLE H-7. PROCESS TIME REQUIREMENTS IN SECONDS (UNLESS NOTED) FOR SYSTEM II

		Eddy Current Test					*Ultrasonic Test*				
Part ID	*Operations*	*Inspection*	*Calibration*	*Handl/ Setu*	*Total Time*	*Hours mo*	*Inspection*	*Calibration*	*Handl/ Setu*	*Total Time*	*Hours mo*
	Scallops:										
1F		400	20	130	550						
2F		400	20	130	550						
3F		400	20	130	550						
4F		400	20	130	550						
4	Total	1,600	80	520	2,200	122.2					
	Boltholes:										
1F		360	30	130	520						
2F		360	30	130	520						
3F		360	30	130	520						
7C		420	30	130	580						
8C		420	30	130	580						
1T		300	30	130	460						
2T		300	30	130	460						
7	Total	2,520	210	910	3,640	202.2					
	Rim Slots:										
1F		480	20	130	630						
2F		640	20	130	790						
3F		480	20	130	630						
8C		960	20	130	1,110						
12C		960	20	130	1,110						
2/3 CPS		60	20	130	210						
6	Total	3,580	120	780	4,480	248.9					
	Angle Cooling										
1T		900	30	130	1,060						
2T		1,200	30	130	1,360						
1/2TS		900	30	130	1,060						
TOBI		450	30	130	610						
4	Total	3,450	120	520	4,090	227.2					
	Rotation Slots:										
2/3 CPS		60	20	130	210						
6/7 CPS		60	20	130	210						
7/8 CPS		60	20	130	210						
8/9 CPS		60	20	130	210						
9/10 CPS		60	20	130	210						
10/11 CPS		60	20	130	210						
11/12 CPS		60	20	130	210						
12/13 CPS		60	20	130	210						
8	Total	480	160	1,040	1,680	93.3					
	Drain Slots										
1F	Total	60	20	130	210	11.7					

TABLE H-7. PROCESS TIME REQUIREMENTS IN SECONDS (UNLESS NOTED) FOR SYSTEM II (Continued)

		Eddy Current Test					Ultrasonic Test				
Part ID	Operations	Inspection	Calibration	Handl/ Setu	Total Time	Hours mo	Inspection	Calibration	Handl/ Setu	Total Time	Hours mo
1	Knife-Edge:										
TOBI	Total	120	20	130	270	15.0					
	Radial Hole										
3T		600	20	130	750						
1/2TS		600	20	130	750						
2	Total	1,200	40	260	1,500	83.3					
	Axial Cooling Slots										
1T		450	20	130	600						
1/2TS		150	20	130	300						
2	Total	600	40	260	900	50.0					
	Web Test Side 1										
1F		270	15	130	415		270	15	130	415	
2F		270	15	130	415		270	15	130	415	
3T		270	15	130	415		270	15	130	415	
4T		270	15	130	415		270	15	130	415	
4	Total	1,080	60	520	1,660	92.2	1,080	60	520	1,660	92.2
	Web Test Side 2										
1F		270	15	230	515		270	15	250	535	
2F		270	15	230	515		270	15	250	535	
3T		270	15	230	515		270	15	250	535	
4T		270	15	230	515		270	15	250	535	
4	Total	1,080	60	920	2,060	114.4	1,080	60	1,000	2,140	118.9
	Bore										
1F		450	120	130	700		450	120	150	720	
2F		450	120	130	700		450	120	150	720	
3F		450	120	130	700		450	120	150	720	
8C		450	120	130	700		450	120	150	720	
1T		450	120	130	700		450	120	150	720	
3T		450	120	130	700		450	120	150	720	
4T		450	120	130	700		450	120	150	720	
7	Total	3,150	840	910	4,900	272.2	3,150	840	1,050	5,040	280.0
	Total 12 Operations	18,920	1,770	6,900	27,590	1532.7	5,310	960	2,570	8,840	491.1

TABLE H-8. SUMMARY OF PROCESSING TIME REQUIREMENTS BY OPERATION FOR SYSTEM II

Operation	*Hours/Month*	*Machines Required*		*Machines Provided*
Eddy Current				
Scallops	122.2	0.79		1
Boltholes	202.2	1.31		2
Rim Slots	248.9	1.62		2
Angle Coolin,	227.2	1.48		2
Rotation Slots	93.3	0.061		
Drain Slots	11.7	0.08	0.79	1
Knife Edge	15.0	0.10		
Radial hole	83.3	0.54		
Axial Cooling Slots	50.0	0.32	0.86	1
Web Test Side 1	92.2	0.60		1
Web Test Side 2	114.4	0.74		1
Bore	272.2	1.77		2
	1,532.7	9.96		13
Standby				1
TOTAL				14
Ultrasonic				
Web Test Side 1 and 2	211.0	1.37		2
Bore	280.0	1.82		2
TOTAL	491.0	3.19		4

The number of inspection machines required was determined by dividing the sum of monthly setup and machine times (Table H-8) by 154 hours per month.

The "Machines Required" column of Table H-8 assumes 100% efficiency on the part of the inspection equipment and average throughput rates for the system. Because of the low processing time demand, the rotation slots, drain slots and knife edge operations were combined and assigned to one inspection machine. The same held true for the radial hole and axial cooling hole operations. The fractional number of machines calculated for each operation were rounded up to allow for machine downtime and other unforeseen inefficiencies. One standby machine was added for the eddy current inspection to provide redundancy for the operations that have only one machine. In the ultrasonic operations two machines will be provided for each operation. In case one machine is down, reduced throughput will be available through the other.

4.5 Design and Construction

The system will incorporate standard and interchangeable components. The design will be modular in nature for simplification and ease of installation.

4.6 Physical Characteristics

There are no special weight limitations that apply to the parts handling system. Loading imposed by the equipment will be in conformance with the requirements for light industrial facilities.

The system will be designed to conform to the specified clear height of 18 ft for the RFC facility.

The parts handling system will be built for conventional industrial use and will be permanently installed.

The equipment will incorporate all necessary safety features in order to protect personnel during installation, operation and maintenance.

4.7 Reliability

System will be designed with sufficient ruggedness and capacity and with the application of standard and interchangeable components in order to achieve a high level of reliability.

Main line conveyor drives, programmable controllers, and microprocessors will be provided in redundancy.

4.8 Maintainability

The conveyor control system will have self test diagnostics to assist in maintenance activities. All major components will be interchangeable in so far as practical.

All conveyor drives, actuators, scanners and other components requiring frequent service will be located for easy access.

4.9 Environmental Conditions

The parts handling system will be designed to operate in a normal maintenance facility environment.

The power and free conveyor will be supported from the overhead structure of the facility.

4.10 Major Components Characteristics

4.10.1 Parts Handling Conveyor System

1. Power roller conveyor to transport modules in tote boxes from the FPI and dimensional inspection areas. The conveyor will be provided with seven stops and right angle transfer mechanisms to divert the boxes onto the surge conveyors. The stops and transfer mechanisms will be automatic and programmed to effect the transfer sequentially from one accumulation conveyor to the next. The conveyor will have two levels (floor and elevated) which will be connected with a vertical lift.

2. Gravity roller conveyors for accumulation prior to induction station. A release-restrain mechanism will be provided at the exit end of each conveyor so that one box is released at a time onto the transfer conveyor. The release mechanism will be actuated remotely by the operator at the induction station. The conveyor will be designed to maintain the box flow through the conveyor without excessive acceleration but with assurance of movement.

3. Power roller transfer conveyor to deliver boxes to the induction station. The conveyor will be actuated on demand by the operator at the induction station. Upon completion of the activities at the induction

station, the empty box will be indexed to a vertical lift device. This device will elevate and transfer the empty box onto the elevated power roller conveyor for transportation to the FPI and dimensional inspection areas.

4. Overhead power and free conveyor for delivery of parts the eddy current and ultrasonic inspection stations. The conveyor will be supported from the facility structure by means of secondary support steel.

   Carriers will be provided to carry a single part. Each carrier will have an identification number that can be recognized by the scanners that will be provided at every decision point throughout the route. The carrier will be configured to carry any of the 21 parts in a stable manner and will allow the part to be unloaded and loaded by the industrial robots.

   At every entry or exit point, the conveyor system will be provided with stops to hold the carriers until the entrance or exit is clear.

   At every decision point a scanner will be provided to read the carrier identification number and communicate the information to the control system which will activate a switch to divert the carrier or allow it to pass to the next decision point.

   Each inspection station will be furnished with a spur that includes a stop at the exact load/unload position. The spur will have sufficient length to accumulate three carriers in addition to the one at the load position. If another carrier is directed to a station when the spur is full, this carrier will be automatically recirculated.

   The load position will contain a device to hold in place the hook of the carrier to facilitate the loading and unloading by the industrial robot. At the completion of the inspection, when the part is placed on the carrier and the robot has retracted, the carrier will be automatically released and another one brought into position.

   After a carrier leaves the area of the inspection stations it will pass by an audit scanner which will communicate the carrier number to the control system. The control system will then assign a lane in the accumulating conveyor section or recirculate the carrier back to the inspection stations in case an inspection was bypassed.

   When all parts of a module are together the conveyor control system will inquire from the inspection master computer system the results of the inspection tests. Modules with parts containing flaws will be routed automatically to the reject unload station. Otherwise the module will be routed to the acceptable parts unload station. After the parts are unloaded, the empty carriers will be routed to the loading station or empty carrier storage track.

5. Gravity roller conveyor for storage containers with rejected parts.

6. Powered roller conveyor to transport loaded containers or pallets with parts destined to the storage/retrieval system. The conveyor will operate intermittently at the command of the operator unloading the system. The conveyor will have two levels (floor and elevated) which will be connected with a vertical lift.

7. Vertical lifts to connect floor mounted conveyors to elevated conveyors. These lifts will be designed to automatically receive, elevate and discharge the loads between the segments of the conveyors.

8. Conveyor control system will be designed to include all the functional requirements described in this section and as required to make a complete integrated system.

4.10.2 Automatic industrial robots will load and unload parts at the inspection stations. The robots will be computer controlled and interfaced with the conveyor control system. They will have multi-axis movement to perform all required positioning functions within the accuracy required by the inspection machines.

The industrial robots will be floor mounted and provided with gripper(s) suitable to handle all parts at each station.

The robots at the ultrasonic inspection stations will be provided with gripper(s) made of noncorrosive material and a compressed air blowoff device.

4.10.3 Rollover devices for parts requiring inspection on both sides. It will have automatic clamping and rollover operations interfaced with the industrial robot. The device will be mounted on a floor supported stand. For the ultrasonic inspection stations, the device will be protected against corrosion due to the wet operation.

4.10.4 High speed laser beam marking machine for inscribing the marking of the "zero point" on the surface(s) of the parts. The machine will also be used to inscribe the part number and serial number if these are not present or unsuitable for machine reading.

The machine will be provided with a fixture to properly secure and position the part to be marked. The markings will be engraved on annuli surfaces. All alpha-numeric characters will be provided in sizes suitable to the surface of the part which will be designated for the engraving. The machine will be provided with a CRT for data input and a microprocessor to automatically control the functions of the engraving.

4.10.5 Part number scanner capable of reading alpha-numeric characters inscribed by the laser beam marking machine. Information read will be transmitted to the inspection master computer system.

4.10.6 Single girder monorail hoist, 500 lb capacity, motorized, 25 ft span, underhung, pendant floor operated, with 50 ft long runway.

4.10.7 Tote boxes 34 in. long, 22 in. wide and 12 in. high for transport of modules from the FPI. The boxes will have dividers for separation of parts. The boxes will be made of high impact plastic or fiberglass. The bottom of the boxes will be flat and suitable for transportation by roller conveyors.

4.11 Summary of Operation

The primary material transport device in this system is a power-and-free conveyor.

The sequence of operations for the system is illustrated in the flow diagram Figure H-24. The equipment configuration is illustrated in Drawing I-2 in Appendix I.

Parts will come from the overhaul area via a 24 in. powered roller conveyor. The parts will be transported in tote boxes 34 in. long by 22 in. wide by 12 in. high. Each box will carry parts for a complete module. The parts will be stacked and separated by dividers. Refer to Figure H-3. The bar coded plate described under System I is not required for System II.

4.11.1 Induction Area

At the induction area, the modules will be transferred onto gravity roller conveyors for buffer storage. These conveyors will have capacity to store a two-day buffer.

The induction operator will release the boxes from the buffer area as necessary in first-in first-out order at the pace required by the inspection process. Upon release, a box will be automatically transported to a position in front of the receiving operator and stop. The operator will remove each part from the box, one at a time, and verify that the "zero" reference point marking exists. This marking will be required on all parts so that the point where the inspection starts becomes fixed. If the "zero" reference point is not present, the operator will remove the part and load it into a machine to have it properly marked.

Next, the operator will read the part number and serial number on a scanner. If the part number and/or serial number are not machine readable, he must reinscribe the number. This will be accomplished by means of a machine located at his station.

When the part number is read by the scanner, the computer will recognize: the part number, the module it belongs to (I, II, III or IV) and the carrier number stationed in front of the operator ready to be loaded. The operator then will load the part on the carrier and release it.

4.11.2 Inspection Station

Upon recognition of the part number, the control system will direct the carrier through all the inspection stations required for the part. A scanner and a switch will be provided at the entrance to each inspection station. The scanner will read the carrier number and communicate this information to the control system which will either actuate the switch to admit the carrier to the inspection station or cause the carrier to proceed to the next station. If the part is admitted, the control system will communicate the part's identification to the robot so that it will adjust as required when unloading the part.

Each inspection station will be provided with a spur to stage three carriers prior to the inspection. If the spur is full and another carrier is assigned to it, the carrier will be automatically recirculated. Upon entering the inspection station, the carrier will proceed and stop at the part unloading position. At this location, a stabilizing device will be automatically actuated to hold the carrier steady. The robot will adjust itself according to the part configuration, advance, grab and remove the part from the carrier and load it onto the inspection machine.

The robot will then retract its arm and the inspection process will begin. Upon completion of the inspection process the robot will remove the part from the machine and place it on the carrier, which will convey it to the next scheduled inspection test.

At the ultrasonic machine, when the inspection is completed, the robot will remove the part from the tank and hold it to allow the water to drip. The part is then subjected to a compressed air blowoff before it is placed back on the carrier.

Some parts require inspection on both sides. A rollover device will be included at these inspection stations. At the completion of the test on the first side of the part, the robot will remove the part and place it in the rollover device. The device will then roll the part over. The robot will pick up the part and place it back in the inspection machine for inspection of the reverse side. At the completion of this test, the part must be once again loaded by the robot and turned over in the rollover device prior to being placed on the conveyor carrier. The carrier will be designed to receive and carry the part so that the same side always faces the robot.

4.11.3 Audit Station

At the completion of the inspection, all carriers will pass through the audit scanner which will communicate with the control system which will assign the carrier to a lane in the accumulating conveyor or recirculate it in case an inspection was bypassed. Each module will be assigned a separate lane. Once all the parts for a module are in the accumulation lane, the control system will inquire from the inspector master computer system whether any part in the module contains flaws.

4.11.4 Rejected Parts Station

Modules with parts containing flaws will be routed to the unload station at the reject area.

An operator at the reject station will unload the entire module into a container, activate the printer for generation of a report indicating the cause of rejection. The report will be placed into the container. An overhead hoist will be provided to remove the containers and stage them for final disposition.

4.11.5 Acceptable Parts Station

Modules with acceptable parts will be routed to the acceptable parts unload station.

An operator will remove the parts and load them in storage containers suitable for the storage/retrieval system available at the depot engine maintenance center. The operator will load only one module per storage container in order to maintain the components of each module together. The storage containers will then be conveyed to the storage area.

The empty carriers from the reject or acceptable unload stations will be routed to the induction station or to the empty carrier storage track.

5. PILOT SYSTEM

5.1 Major Components List

The parts handling subsystem is comprised of the following components:

- 2 Gravity roller conveyors, 42 in. wide, for storage of pallets with tote boxes received from the overhaul operations.
- 1 Gravity roller conveyor, 42 in. wide for storage of empty pallets.
- 20 Mobile carts with caster wheels for handling tote boxes through the inspection stations.

1 Single rail hoist with 500 lb capacity, 12 ft span and 20 ft runway.

1 Gravity roller conveyor, 36 in. wide, to accumulate pallets exiting the RFC area.

1 Laser beam marking machine for inscribing "zero point" and part and serial numbers.

1 Part number scanner at the induction station.

1 Drip stand and blowoff until for the ultrasonic inspection station.

50 Tote boxes.

5.2 Government Furnished Property List

The pallets or other suitable containers to transport the inspected modules to the storage/retrieval system of the repair facility will be furnished by the depot repair facility.

5.3 Item Definition

The parts handling subsystem will provide the means to stage and transport parts received from the overhaul operation throughout the RFC inspection process until they are placed back into storage subsequent to the inspection tests.

This system will consist of gravity roller conveyors, mobile carts, hoist and containers (tote boxes).

5.3.1 Item Diagrams

Drawing I-3, Appendix I, provides a conceptual layout of the proposed parts handling subsystem. The sequence of parts processing is similar to that shown on Figure H-22, with the exception that mechanized part handling between stations is not provided. Figure H-23 displays a conceptual transport container (tote box).

5.3.2 Interface Definition

The interfaces between the inspection equipment and parts handling are manually performed, i.e., an operator will manually handle the parts through all the steps of the process.

5.4 Performance

The parts handling subsystem has no specified throughput due to the experimental nature of this concept.

Components of the engine to be processed consist of 21 disks or spacers grouped into 4 modules. The components of each module will remain together throughout the transportation and processing steps.

The system operation will be based on 7 hours per day and 22 days per month for a total of 154 hours per month.

Modules will be supplied to the inspection stations on a first-in, first-out basis.

This system is configured on the same basis as System I, i.e., each eddy current or ultrasonic machine can perform all inspections for any part. Parts handling in this system is not mechanized.

Two eddy current and one ultrasonic inspection machines will be provided. This number of machines was selected as a proportional derivative of System I (1/2). Although throughput was not a criterion for determining the number of inspection stations, this system will have a capacity approximately one-third of the capacity of System I.

5.5 Design and Construction

The system will incorporate standard and interchangeable components.

5.6 Physical Characteristics

There are no special limitations that apply to the part handling system.

5.7 Major Components Characteristics

5.7.1 Parts handling system consists of the following:

1. Gravity roller conveyors for accumulation prior to induction station. The conveyor will be designed to maintain the pallet flow through the conveyor without excessive acceleration but with assurance of movement.

2. Gravity roller conveyor for accumulation of empty pallets.

3. Mobile cart with four wheel casters for handling tote boxes through the inspection stations. The cart table top will be of sufficient size to accommodate one tote box and will be 24 inch high.

4. Single girder monorail hoist $\frac{1}{4}$-ton capacity, motorized, 12 ft span, underhung, pendant floor operated, with 20 ft long runway.

5. Gravity roller conveyor for accumulation of pallets with inspected modules that are to be transferred to the storage/retrieval system.

5.7.2 High speed laser beam engraving machine for inscribing the marking of the "zero point" on the surface(s) of the parts. The machine will also be used to inscribe the part number and serial number if these are not present or not suitable for machine reading.

The machine will be provided with a fixture to properly secure and position the part to be marked. The markings will be engraved on annuli surfaces.

All alpha-numeric characters will be provided and in sizes suitable to the surface of the part which will be designated for the engraving.

The machine will be provided with a CRT for a data input and a microprocessor to automatically control the functions of the engraving.

5.7.3 Part number scanner capable of reading alpha-numeric characters inscribed on the disks or spacers. Information read will be transmitted to the inspection master computer system.

5.7.4 Drip stand for ultrasonic inspection station. Stand will be built of corrosion-proof material and be of sufficient height to allow the dripping to flow back to the tank. The stand will be supplied with a compressed air blowoff gun.

5.7.5 Tote boxes 34 inch long, 22 inch wide and 12 inch high for transport of modules throughout the system. The boxes will have dividers for separation of parts. The boxes will be made of high impact plastic or fiberglass. The bottom of the boxes will be flat and suitable for transportation by roller conveyor.

5.8 Summary of Operation

The sequence of operations is similar to that of System I as shown in flow diagram Figure H-22. The equipment configuration and flow of parts is shown in Drawing I-3.

Parts will come from the overhaul area in tote boxes on pallets transported by fork truck. The tote boxes will be similar to those described for System I. Refer to Figure H-23. The pallets will be unloaded on gravity roller storage conveyors.

An operator at the induction station will remove each part from the tote box, one at a time, and verify that the "zero" reference point exists. If this marking is not present, the operator will load the part into an engraving machine to have it properly marked.

Next, the operator will read the part number and serial number with an instrument similar to the reader located at each inspection station, to insure readability. If the part number and/or serial number are not machine readable, he must re-inscribe the number. This will be accomplished by means of a machine located at this location.

When the identification task is completed the operator will load the parts into a tote box on a mobile cart. Parts will be placed into the tote box retaining the module separation that was established in the FPI area. The carts will be staged in an area adjacent to the inspection stations.

The carts will be moved to the inspection station as required. The inspection operations will be similar to those described for System I.

Once all the inspections are complete for a module, the cart will be moved to the auditing station.

At the auditing station an operator will inspect the reports from the inspection station. Modules containing parts with flaws will be moved to the reject storage area and staged for final disposition.

Parts of modules without flaws will be transferred to a storage container and staged for transport to the storage/retrieval system.

6. QUALITY ASSURANCE PROVISIONS

The responsibility for performing all required tests/verifications rests with the supplier. The U.S. Government reserves the right to witness or separately perform all tests required.

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX I
FACILITY LAYOUT AND SPACE REQUIREMENT SPECIFICATION

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APPENDIX I

FACILITY LAYOUT AND SPACE REQUIREMENTS

1. SCOPE

The layout and space requirements were based on the following considerations:

- Number of inspection machines
- Inspection machine grouping
- Method of parts transport
- Storage and transport buffers
- Office areas
- Aisles and circulation areas.

It was assumed that facility constructions will be similar to that of the existing maintenance facilities and will provide a clear height of 18 feet.

The layouts for the facility for parts inspection and handling systems were configured under the following three alternatives:

System I which consists of six eddy current and three ultrasonic inspection stations with manual part loading and unloading. The facility will contain the support facilities such as computer room, storage, offices and maintenance/spare parts storage.

The system capacity is to inspect 21 parts of 100 engines per month or 2100 parts per month.

System II which consists of 14 eddy current and four ultrasonic inspection stations with fully automatic parts loading and unloading. The facility will contain the support facilities as described for System I.

The system capacity is to inspect 21 parts of 200 engines per month or 4200 parts per month.

Pilot System which consists of two eddy current and one ultrasonic inspection stations with manual parts loading and unloading. The facility will have the support facilities as described for System I. The system has no specified capacity as its primary function is to serve as a pilot operation of the inspection equipment.

It was assumed that the facility for Systems I and II will be adjacent to the existing Kelly AFB engine repair facility, and that all utilities and services will be readily available at the boundary or nearby the proposed facility. The space for the Pilot System is assumed available within the existing repair facility.

2. APPLICABLE DOCUMENTS

The facility will be designed and constructed in compliance with all applicable military and federeal specifications.

3. ITEM DEFINITION

The facility will be designed and constructed with all the necessary services and utilities and any other features required to adequately house the inspection and part handling equipment.

3.1 Item Diagrams

Figures I-1, I-2 and I-3 represent conceptual layouts of the proposed facility under the three separate concepts.

3.2 Interface Definition

The utilities required for the facility, such as electric power, compressed air, water and drainage, will be interfaced with the source mains located in the existing facility.

The construction of the new facility will not cause disruption to the environment or operational processes of existing facility due to dust, noise or other affecting factors.

The facility structure framing, foundation, roof and wall systems will be interfaced with the existing facility system.

4. REQUIREMENTS

4.1 System I

As explained in Appendix H the number of inspection machines required for this level of throughput was determined to be:

6 Eddy Current Inspection Machines

3 Ultrasonic Inspection Machines

It was also determined that each eddy current machine would be capable of performing all eddy current inspections for all parts and each ultrasonic machine would be capable of performing all ultrasonic inpections for all parts. Therefore, the ultrasonic operations had to be located in a position that would enable them to receive parts from any eddy current machine.

A number of alternatives, which grouped the inspection machines into two or more machines per work center, were evaluated. However, it was determined that configuring independent work stations for each machine provided the most efficient layout in terms of flexibility and redundancy.

4.1.1 Layout

The layout was initiated by organizing the inspection stations in two rows, one for the eddy current and the other for the ultrasonic machines.

The flow of parts will be reversed at the end of the eddy current inspection in order to provide a more compact alignment of the equipment.

Storage for incoming parts will be provided in an area ahead of the inspection stations. Storage for inspected parts will be provided in the central part of the facility with access aisles on both sides for fork truck traffic to supply pallets or retrieve inspected modules that have been rejected.

The layout provides for an eight foot aisle on the external perimeter for access to the equipment.

Conveyors transporting material to or from the facility will be elevated to avoid obstruction of the access aisles and operations external to the RFC inspection process.

The facility layout for System I is shown in Figure I-1.

4.1.2 Space Requirements

The facility as proposed requires an approximate area of 12,000 ft^2. The space allocation was determined by initially arranging the equipment in a manner conducive to good material flow and space utilization.

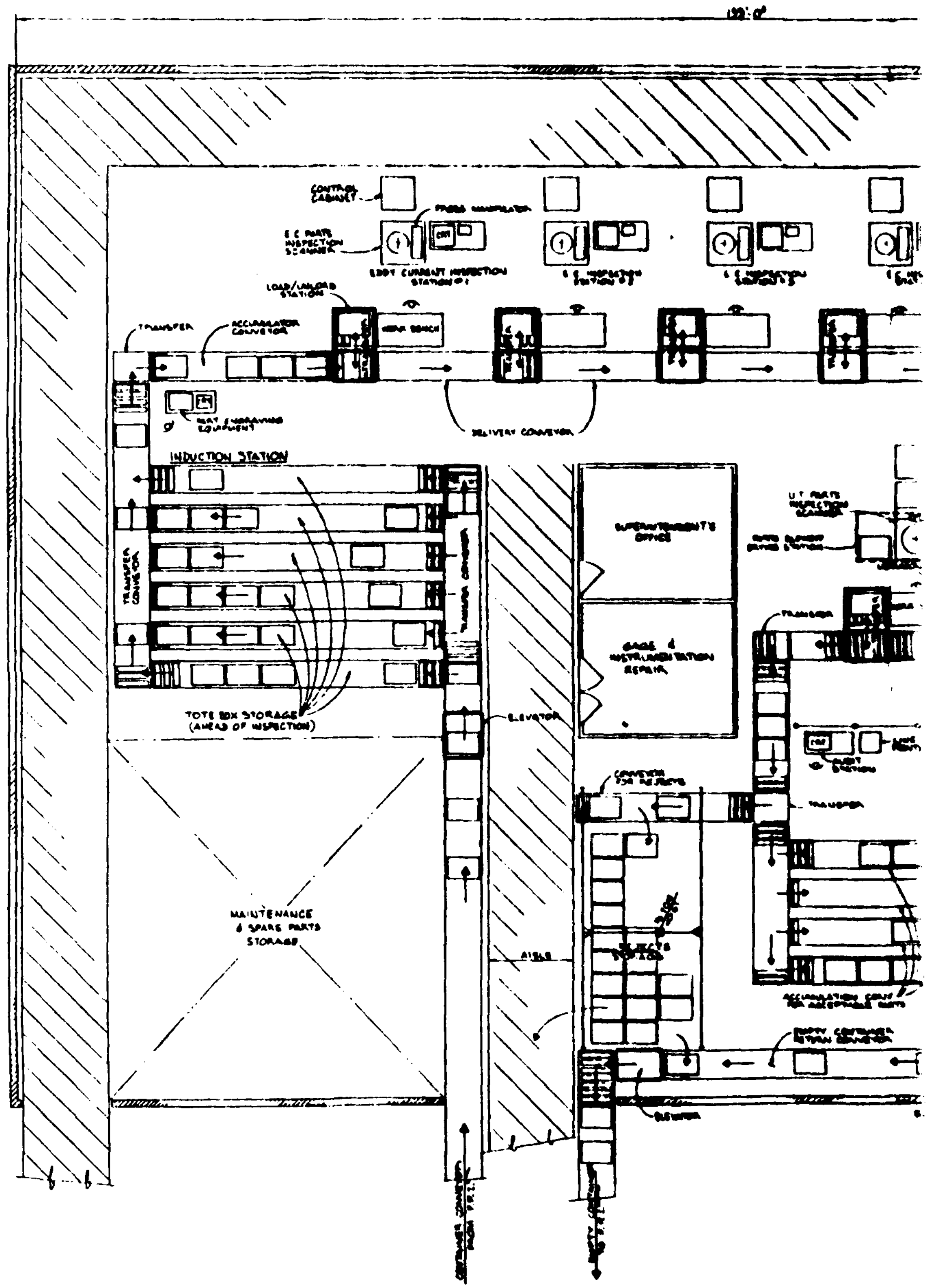
Each inspection station will contain the inspection scanner, its control cabinet, a work bench, and a desk with CRT. Ultrasonic stations will have a floor mounted drip stand. Transport of parts between stations will be accomplished by conveyor.

Storage space was provided for a three-day supply of parts in the Receiving (Induction) Area.

The outgoing parts area contains separate storage areas for acceptable and rejected parts, to ensure that the parts are not mixed. Since none of the operations in this area require a full-time operator, this will also enable the "banking" of parts, so that multiple operations may be performed by one person.

Areas were assigned to various functions as follows:

	Square Feet
Receiving and Storage	900
Inspection Stations	4,600
Sorting and Storage	1,300
Computer Room	800
Maintenance/Spare Parts Storage	1,000
Office and Gage Room	400
Aisles and Circulation	3,000
Total	12,000



CONTROL CABINET
PRESS MANIPULATOR
E C PARTS INSPECTION SCANNER
EDDY CURRENT INSPECTION STATION # 1
E C INSPECTION STATION # 2
E C INSPECTION STATION # 3
LOAD/UNLOAD STATION
WORK BENCH
TRANSFER
ACCUMULATOR CONVEYOR
PART ENGRAVING EQUIPMENT
DELIVERY CONVEYOR
INDUCTION STATION
TRANSFER CONVEYOR
TOTE BOX STORAGE (AHEAD OF INSPECTION)
ELEVATOR
MAINTENANCE & SPARE PARTS STORAGE
AISLE
SUPERINTENDENT'S OFFICE
GAGE & INSTRUMENTATION REPAIR
U.T. PARTS INSPECTION SCANNER
CONVEYOR FOR REJECTS
REJECTS STORAGE
ACCUMULATION CONV. FOR ACCEPTABLE PARTS
EMPTY CONTAINER RETURN CONVEYOR

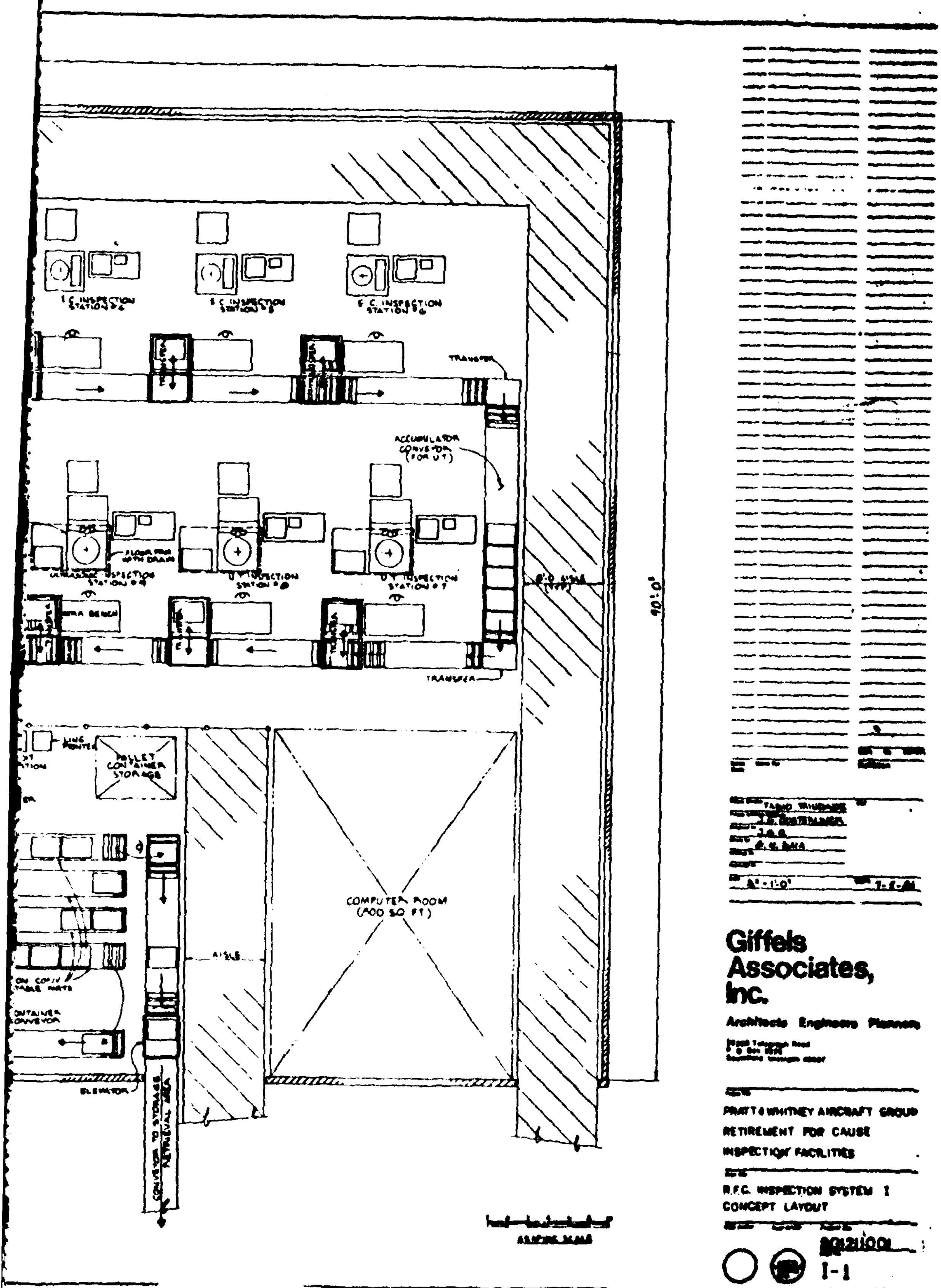


Figure I-1. RFC Inspection System I Concept Layout

4.2 System II

The number of inspection machines required for this level of throughput was determined to be:

14 Eddy Current Inspection Machines
4 Ultrasonic Inspection Machines

At this processing level, it was determined that parts loading should be automatic (by means of industrial robots) and that inspection machines should be dedicated to a single inspection operation wherever practical.

A power and free conveyor system will be used to transport individual parts between inspection stations: therefore, a specific relationship among the inspection machines was not required.

In order to satisfy the redundancy and throughput requirements, each station was equipped with its own robot.

4.2.1 Layout

The layout for System II was initiated by organizing the inspection stations in three rows of six machines occupying approximately one-half of the facility.

Storage for incoming parts will be provided ahead of the inspection and induction stations. Storage for inspected parts will be provided on overhead conveyor spurs in the central part of the facility. A separate staging and storage area for rejected modules awaiting disposition will be provided in one corner of the facility.

The layout provides for an eight-foot aisle on the external perimeter of the facility for access to the equipment and to the staging and storage areas.

Roller conveyors transporting material to or from the facility will be elevated to avoid obstruction of the access aisles and operations external to the RFC Inspection process.

The facility layout for System II is shown in Figure I-2.

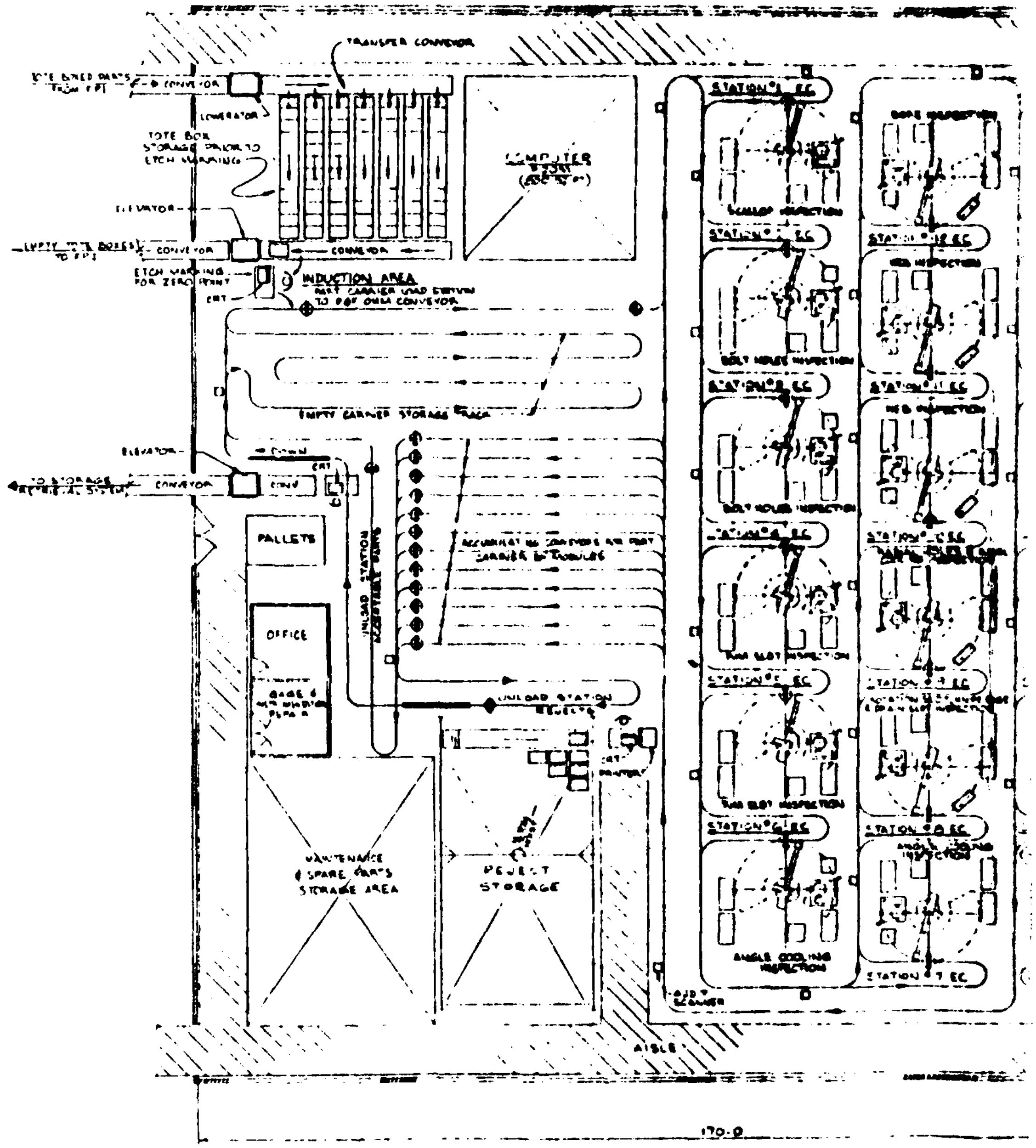
4.2.2 Space Requirements

The facility as proposed requires an approximate area of 29,000 ft^2. The space allocation was determined by grouping the inspection equipment and ancillary functions to facilitate the path of the conveyor and provide for good material flow and space utilization.

Each inspection station will contain the inspection scanner and its control cabinet; an industrial robot, its control cabinets, and a fixture stand; and an instrumentation table. Stations that inspect both sides of parts will have a part roll-over device. Transport between stations will be accomplished by power and free conveyor.

Storage space will be provided for a two-day supply of parts in the Receiving (Induction) Area.

Accumulating conveyors will be provided to store parts on carriers once all inspections are completed. A separate area is provided to store rejected parts awaiting disposition.


TRANSFER CONVEYOR
CONVEYOR
ELEVATOR
TOTE BOX STORAGE PRIOR TO ETCH MARKING
COMPUTER
ELEVATOR
CONVEYOR
INDUCTION AREA
ETCH MARKING FOR ZERO POINT
CRT
EMPTY CARRIER STORAGE TRACK
ELEVATOR
TO STORAGE RETRIEVAL SYSTEM
CONVEYOR
PALLETS
UNLOAD STATION ACCEPTABLE PARTS
OFFICE
UNLOAD STATION REJECTS
MAINTENANCE & SPARE PARTS STORAGE AREA
REJECT STORAGE
AISLE
170'-0
STATION #1 EC
SCALLOP INSPECTION
BOLT HOLES INSPECTION
TWO SLOT INSPECTION
ANGLE COOLING INSPECTION
BORE INSPECTION
STATION #7 EC

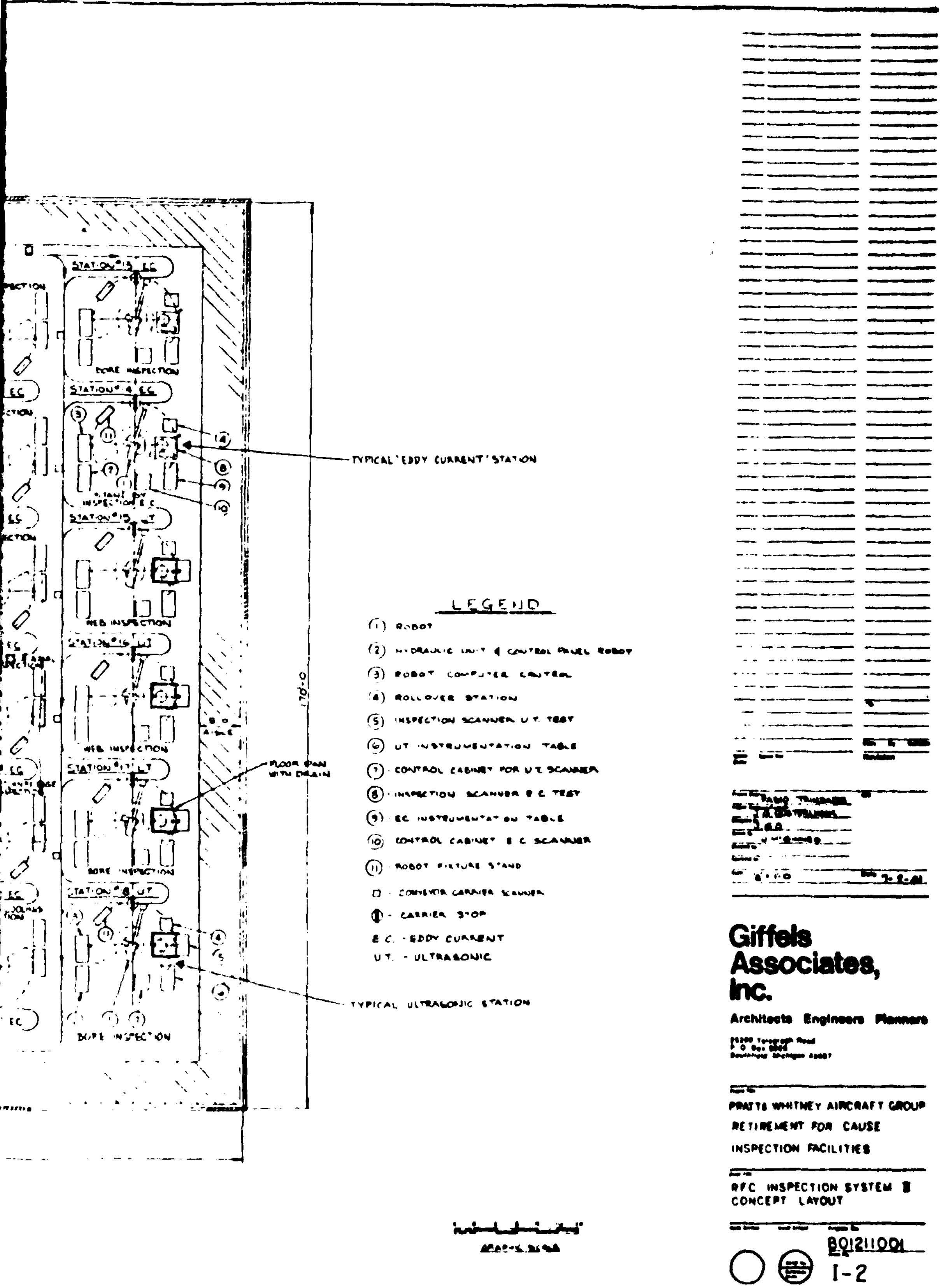


Figure I-2. RFC Inspection System II Concept Layout

Areas were assigned to the various functions as follows:

	Square Feet
Receiving and Storage	4,000
Inspection Stations	12,800
Sorting and Storage	4,500
Computer Room	800
Maintenance/Spare Parts Storage	1,200
Office and Gage Room	400
Aisles and Circulation	5,300
Total	29,000

4.3 Pilot Operation Facility

4.3.1 Layout

This layout was established by separating the three inspection stations and the computer room from the area for receiving, sorting and storage for incoming and outgoing modules by an aisle.

The layout provides for an isolation of the sensitive computer and inspection station equipment from the activities associated with the material handling in the receiving and storage areas.

The layout of the proposed facility is shown in Figure I-3.

4.3.2 Space Requirements

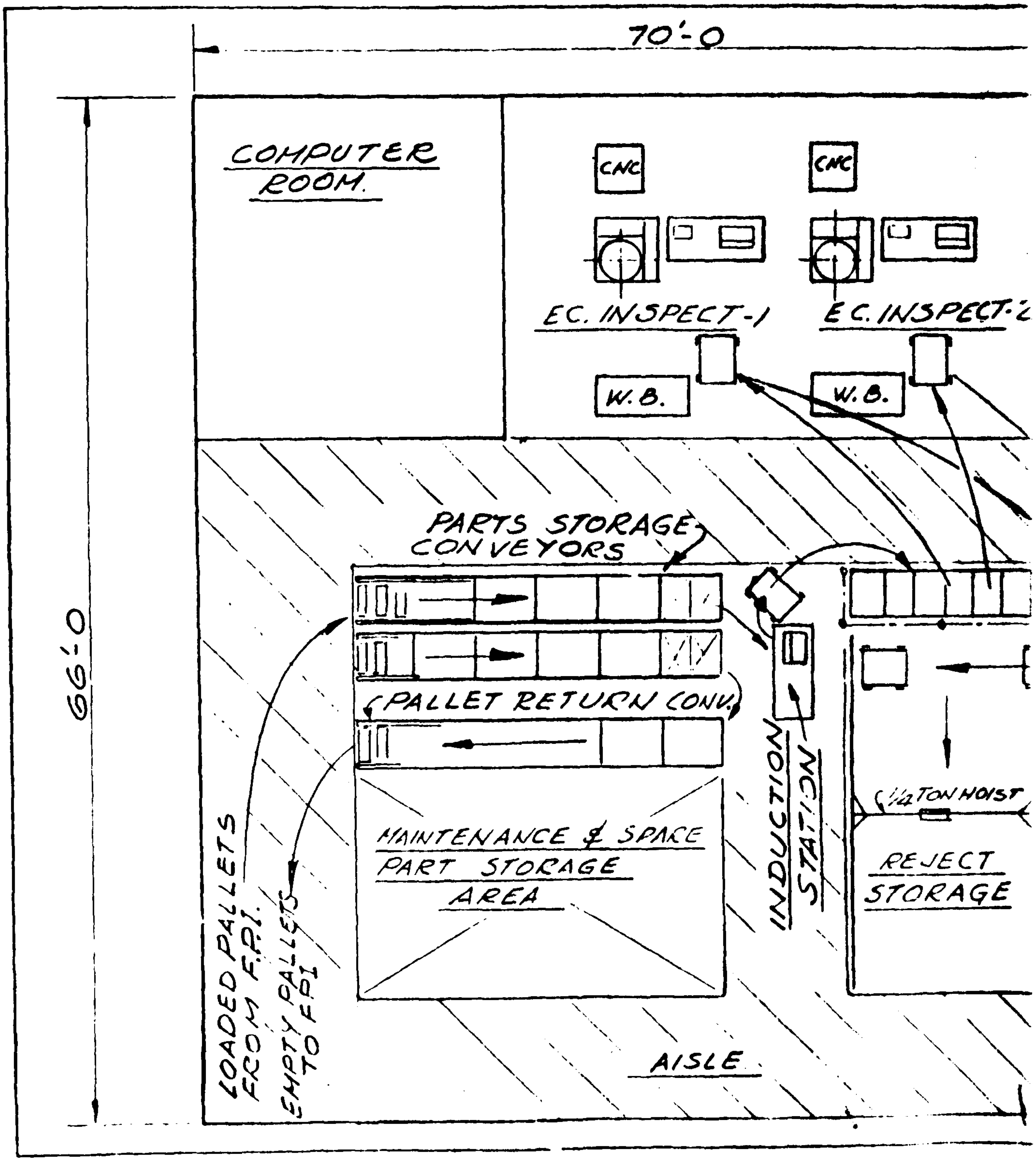
The facility as proposed requires an approximate area of 4,600 ft^2. The space allocation was determined by arranging the equipment in a manner suitable for convenient material flow and access.

Areas were assigned to the various functions as follows:

	Square Feet
Receiving and Storage	400
Inspection Stations	1,150
Sorting and Storage	850
Computer Room	450
Maintenance/Spare Parts Storage	350
Aisles and Circulation	1,400
Total	4,600

Giffels Associate

made by JG. OOSTERINCK chkd. by
date 6-22-81. date



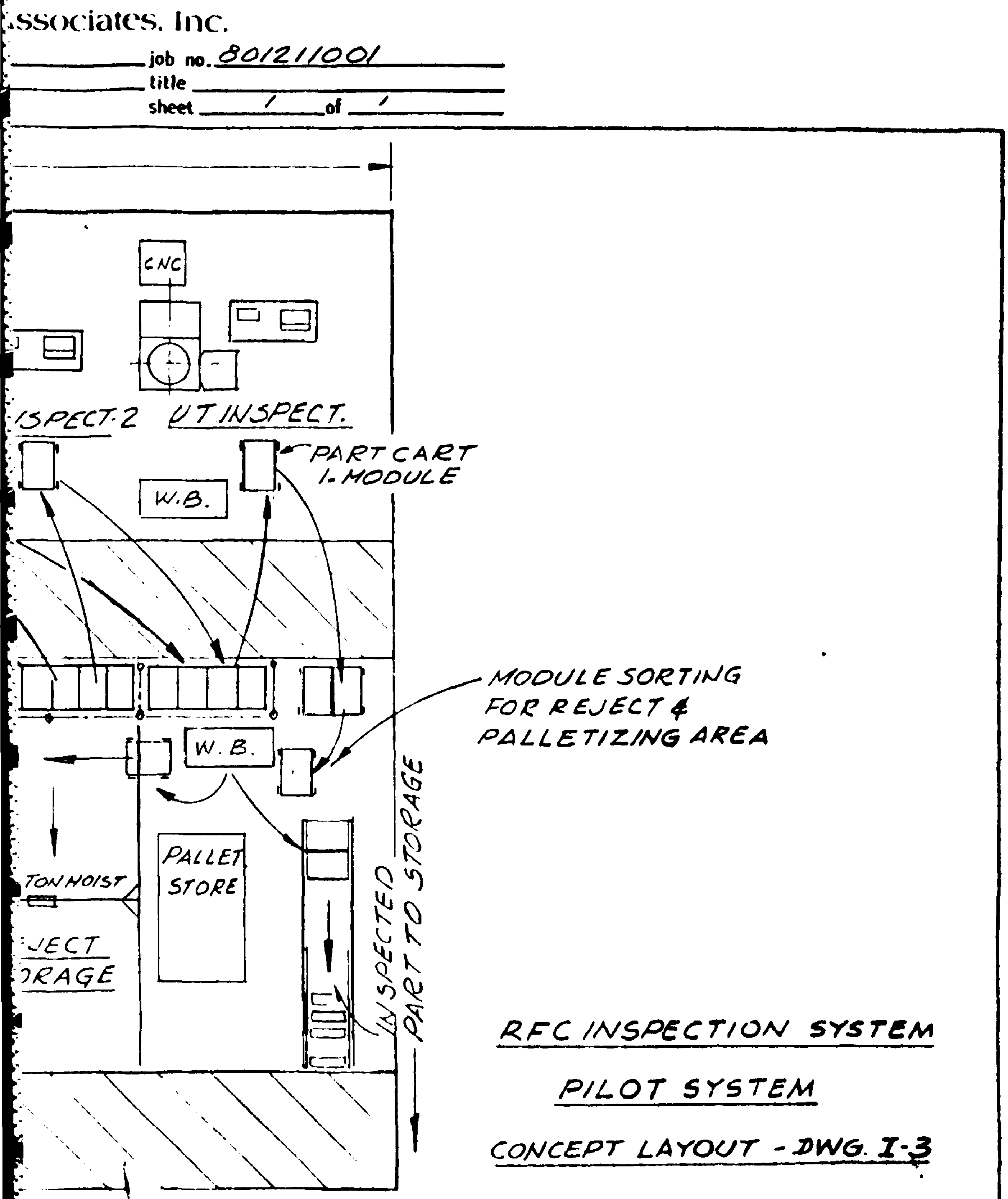


Figure I-3. RFC Inspection System Pilot System Concept Layout

5. DESIGN AND CONSTRUCTION

In addition to all applicable standards and specifications that the facility will conform to, the following design and construction characteristics will be provided:

(1) Building walls and roof will be compatible to that of the existing facility.

(2) Floor will be concrete with surface sealed to control dusting.

(3) Doors and windows will be of material and finish compatible to that of the existing facility.

(4) Building height will be 18 feet clear to the bottom of the roof supporting structure.

(5) Building structure and foundation will be designed to support the hanging loads of the conveyors and utilities in addition to the normal building loads.

(6) Computer Room will be provided with: raised floor; ceiling independent from the building; temperature and humidity control; two levels of lighting, high and medium; fire protection with an audible alarm, suitable for the computer equipment.

(7) Emergency power will be provided to maintain uninterruptable power supply (UPS) for the computer equipment.

(8) Cable trays will be provided for power, utilities and communication lines and drops for equipment connections.

(9) Low voltage power distribution system will be provided.

(10) Heating and ventilation will be provided for personnel comfort range with filtration to control dust in the environment.

(11) Compressed air system with distribution to the equipment will be provided at normal plant operating pressure.

(12) Water distribution system for the tanks of the ultrasonic inspection stations and floor drains will be connected to existing sewer system.

(13) Telephone and electrical receptacles will be installed at all convenient locations.

(14) Low level general lighting with task lighting localized at each station will be provided.

RETIREMENT FOR CAUSE INSPECTION SYSTEM DESIGN

APPENDIX J
QUANTITATIVE NDE METHODS

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

APPENDIX J

EVALUATION OF ADVANCED NDE METHODS

1. STATEMENT OF PROBLEM

Retirement for Cause (RFC) is a new approach to extending the life of structural components and thereby gaining the concomitant economic benefits. Such a strategy depends upon the ability to determine the remaining life of individual components. Each part can then be deployed until this life is expended rather than being removed from service at an earlier time, as conservatively determined by a statistical distribution of lifetimes expected for similar parts. The lifetime prediction can be made in either of two ways. A proof test methodology can be established to ensure that the part will last for a time interval greater than that before the next opportunity for proof test. Alternatively, nondestructive evaluation (NDE) methods can be used to determine the sizes of the flaws present, lifetimes may then be predicted from appropriate failure models, and finally a decision can be made as to whether this life exceeds the time before the next opportunity for inspection by a suitable safety margin.

In many cases, the latter approach is favored for a variety of reasons, and the overall cost benefits depend upon the accuracy with which flaws are sized by the inspection technique. The ideal technique, which accepts all flaws less than a predetermined critical size and rejects all those greater than this critical size, produces maximum economic benefits. The benefits diminish, and can even become negative, as the technique becomes less precise and the number of false accepts and false rejects increase. Thus, obtaining quantitative, nondestructive flaw size predictions is an important prerequisite for a successful RFC system.

The purpose of this report is to provide an assessment of the readiness of quantitative NDE techniques for inclusion in the present and/or future generation inspection systems for RFC. The report is comprised of four sections. The present section contains brief introductory material. In Section 2, the capabilities of the presently available methods are estimated. This forms a baseline against which the potential improvements of quantitative NDE techniques can be judged. In Section 3, the present status of these quantitative NDE techniques are reviewed. Section 4 concludes the report by recommending programs for bringing the quantitative NDE techniques to a level suitable for incorporation into an RFC system. Therein it is recognized that techniques can be classified into three categories according to the time frame in which they can be applied. Included are discussions of techniques which have been evaluated sufficiently to be immediately incorporated into a system; techniques which, with suitable development, should be ready in a few years and might be added to a first generation system as modular add-ons, and techniques to be considered for incorporation in second generation systems. The majority of the techniques are found to fall in the second category.

In anticipation of the generic need for quantitative NDE, the Air Force, along with the Defense Advanced Research Projects Agency, established a research program directed towards developing a national capability in this area in 1974. The major portion of the data included in this report is drawn from the results of that work. Results from other programs are also incorporated as appropriate.

Before discussing specific techniques, it is necessary to review the flaw types and locations that need to be inspected. This is particularly important for the case of turbine rotor components, since the geometric complexities of these parts can restrict applicability of certain techniques. Due to the variability of shapes and dimensions from component to component and engine to engine, it is not efficient to discuss detection of critical flaws on a part by part basis. Rather, it is more fruitful to consider a generic component, and generic flaw types within that component, as the basis for discussion. To this end, Figure J-1 represents a composite sketch of a typical F100 rotor component. Figure J-2 shows generic flaw types that might be expected within that component. All discussion in this report will be given in the context of these two figures.

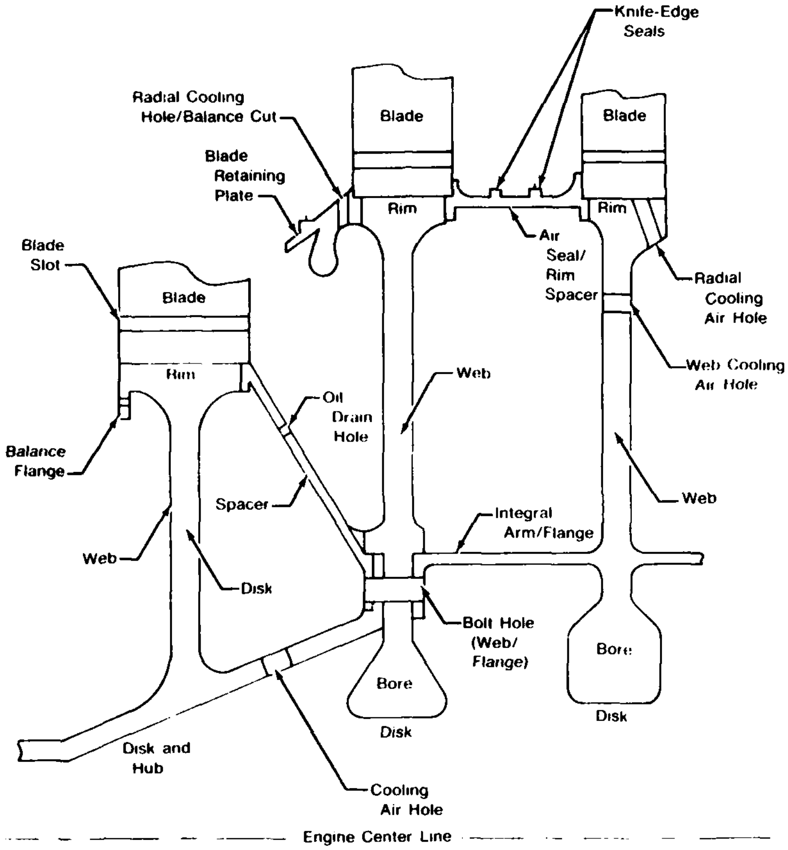

Figure J-1. Composite Sketch of Typical F100 Rotor Components (Not All Features on All Parts) (Figure from P&WA)

2. ESTIMATION OF CAPABILITIES OF PRESENT METHODS

The capabilities of present methods are limited by several factors, which include instrumentation, intended measurement procedures, intended data interpretation procedures, and the degree to which deviations from these intended procedures occur (i.e., reproducibility of operator and/or measurement system). The available instrumentation defines a baseline level of performance which is degraded as the other factors deviate from optimum conditions. For the case of turbine rotor components, a study to ascertain the combined influence of all of these effects, as they exist in field practice today, is underway at Martin-Marietta under the direction of Ward Rummel. Unfortunately, none of this data is available at the time of preparation of this report. Data doubtless exists within the proprietary records of the major engine manufacturers. Unfortunately, this is not in the public domain, and again will not be considered. Fortunately, two major programs for the eddy current inspection of boltholes are in progress, and the data that they have produced will be used to define the capability of the eddy current technique. No such programs using ultrasonics are known to the authors, and so educated guesses will be offered in that area. Other forms of energy will not be considered since the majority of the candidate advanced techniques are either ultrasonic or eddy current.

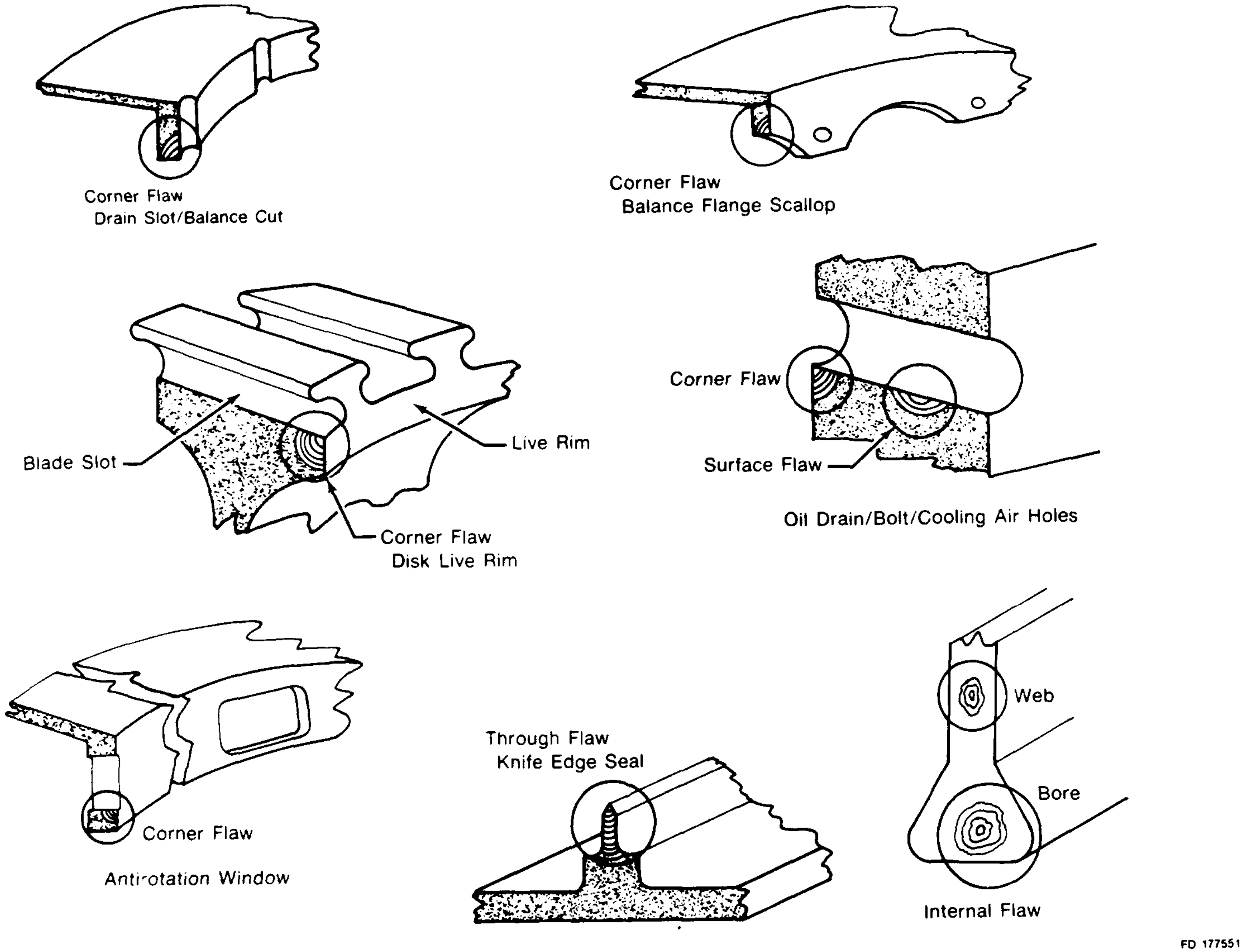

Figure J-2. Composite Sketch of Typical Rotor Component Flaw Types (Not All Featues on All Parts) (Figure from P&WA)

2.1 Eddy Current Inspection

The two eddy current programs cited above are "Quantitative Eddy Current NDE/Bolthole Inspection," Contract F33615-77-C-5218, performed by Adaptronics, Inc., and "Cost/Risk Analysis for Disk Retirement," Contract F33615-78-C-5005, performed by Failure Analysis Associates. In neither case has the final report been issued. The data herein is taken from the second interim report of the former contact (9/77-12/79) and the second through seventh interim reports (12/78-3/80) of the latter contract.

By way of brief summary, the Adaptronics effort was devoted to the development of an automatic capability for determining flaw geometries. As a part of that effort, an extensive data base was collected consisting of eddy current responses from both EDM notches and in-service generated fatigue cracks in TF33 turbine disks. The probe used was a special three-coil probe described below. The Failure Analysis Associates effort is directed towards verifying the basic technologies and methodologies for RFC, rather than towards improving the state of the art of eddy current technology. However, as a part of their effort, five independent sets of eddy current scans of boltholes in third stage turbine disks in the TF33 were made and compared to replication and destructive measurements of the size of the actual fatigue cracks present in those holes. This provides a major data base for evaluating today's capabilities. The sensitivity and reliability of eddy current techniques, as indicated by these two programs, are presented below.

2.1.1 Adaptronics Conclusions

Eddy current inspection of the boltholes was made with a Nortec NDT-15 eddy current scope, a special probe consisting of three coils connected electrically in series and spatially in the same circumferential plane at 120 deg intervals, and a Nortec PS-2 mechanical scanner. The scanner pitch rate was 0.025 in. of travel per revolution, so that one of the three coils would pass over an axial flaw every 0.0083 in. of axial translation. Coil diameter was 0.125 in., and measurements were made at frequencies of 100 kHz, 200 kHz and 2MHz (electromagnetic skin depths of 0.068 in., 0.031 in., 0.016 in., respectively). The coils were mounted on a 0.625-in. dia probe.

Experimental samples consisted of boltholes in TF33 turbine disks. Two were in-service disks containing fatigue cracks. From a replication analysis, a relationship of $\ell = 11.12 \exp(0.031 \times)$ was established where ℓ is the surface length and $\times$ is the maximum depth of the crack, each measured in units of 10^{-3} in. Three disks contained EDM notches to be used for calibration. These had a width of 0.006 in., lengths ranging from 0.020 in. to 0.875 in., and depths ranging from 0.010 to 0.300 in. Tables J-1, J-2 and J-3 give their individual dimensions.

It was concluded from an experimental comparison that EDM notches and cracks produced responses that were virtually identical. It was also concluded that the response was essentially independent of frequency in the range selected, and hence 500 kHz was selected as a standard frequency.

Sensitivity of the system (including an automatic crack detector) was not completely established. The smallest flaws reported were detected. For the EDM notches, this size was 0.020 in. long by 0.005 in. deep. For the fatigue cracks, this was 0.010 in. long by 0.010 in. deep. It can be speculated that smaller flaws could have been detected, particularly in view of the fact the connecting three coils in series reduced the sensitivity of each individual coil.

TABLE J-1. EDM NOTCH DIMENSIONS IN CALIBRATION DISKS (DATA SOURCE: ADAPTRONICS)

Rectangular (Disk 4S5212)		
Bolthole	*Length (in.)*	*Depth (in.)*
1	0.030	0.013
2	0.030	0.015
3	0.051	0.015
4	0.062	0.015
5	0.081	0.029
6	0.111	0.036
7	0.209	0.060
8	0.303	0.100
9	0.485	0.127
10	0.755	0.182

TABLE J-2. EDM NOTCH DIMENSIONS IN CALIBRATION DISKS (DATA SOURCE: ADAPTRONICS)

Semi-Elliptical (Disk 4P5189)		
Bolthole	*Length (in.)*	*Depth (in.)*
1	0.037	0.011
2	0.047	0.019
3	0.076	0.027
4	0.118	0.044
5	0.236	0.066
6	0.300	0.097
7	0.461	0.138
8	0.603	0.208
9	0.671	0.282
10	0.875	0.300

TABLE J-3. EDM NOTCH DIMENSIONS IN CALIBRATION DISK 4R7426 (DATA SOURCE: ADAPTRONICS)

Category	ID	Desired Length	Desired Depth	Actual Length	Actual Depth
	1	0.020	0.010	0.021	0.005
	2	0.020	0.020	0.020	0.020
	3	0.020	0.030	0.020	0.020
	4	0.020	0.040	*	
	5	0.020	0.050		
	6	0.020	0.080	—	—
	7	0.020	0.100	—	—
	8	0.030	0.010	0.028	0.008
	9	0.030	0.020	0.028	0.010
	10	0.030	0.030		
	11	0.040	0.010	0.040	0.009
	12	0.040	0.020	0.041	0.015
	13	0.040	0.030	0.041	0.019
	14	0.050	0.010		
	15	0.050	0.020	0.049	0.013
	16	0.050	0.030	0.049	0.016
	17	0.080	0.010	0.075	0.009
	18	0.080	0.020		0.014
	19	0.080	0.030	0.082	0.020
	20	0.120	0.010	0.118	0.006
	21	0.120	0.020	0.118	0.012
	22	0.120	0.030	0.118	0.016
	23	0.350	0.010	0.342	0.008
	24	0.350	0.020	0.340	0.017
	25	0.350	0.030	0.343	0.022
	26	0.350	0.040	0.330	0.030
	27	0.350	0.050	0.343	0.041
	28	0.350	0.080	0.343	0.070
	29	0.350	0.100	0.343	

*Dashes indicate actual dimension was not measurable because of tear in the rubber replica.

A statistically significant number of opportunities was not available to establish a probability of rejection vs flaw size curve. Instead, a receiver operating characteristic curve is presented in their report which is a plot of probability of false rejects vs the probability of correct detection with the threshold setting of the detector as a parameter. As shown in Figures J-3 and J-4, each of these parameters increases monotonically as the threshold decreases, as would be expected.

Proper interpretation of these receiver operating characteristics curves depends upon a definition of the probabilities plotted along the two axes. For the in-service disks, the probability of detection was taken as the number of cracks detected divided by the total number of cracks inspected, as determined from the replicas. For the disks with EDM notches, the same definition was applied where the known notch location replaced the replica results in determining the total number of opportunities. In each case, the probability of false alarm was taken as the number of false alarms divided by a number on the order of 24,000, where the latter number is equal to the product of the number of boltholes per disk (10), the number of probe rotations per bolthole (40), and the number of possible responses per rotation (60). Thus, each of 60 resolvable angular orientations of the probe in each rotation was viewed as an opportunity for detection. The very low probability of false alarm in any given resolution element resulted from the large number of detection opportunities in each bolthole.

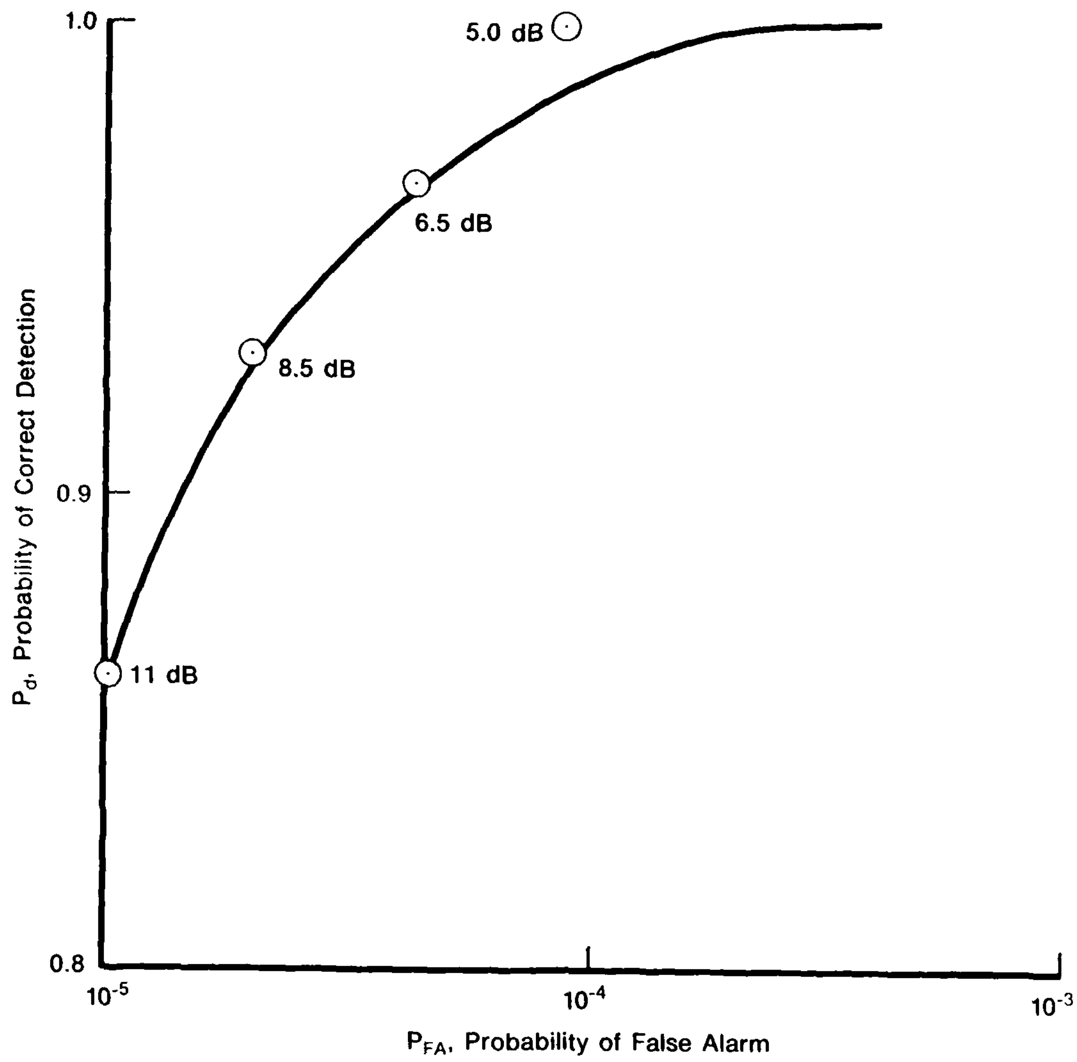

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Figure J-3. Receiver Operating Characteristic Curve of Automatic Crack Detector for EDM Notches. (Figure from Adaptronics, Inc.)

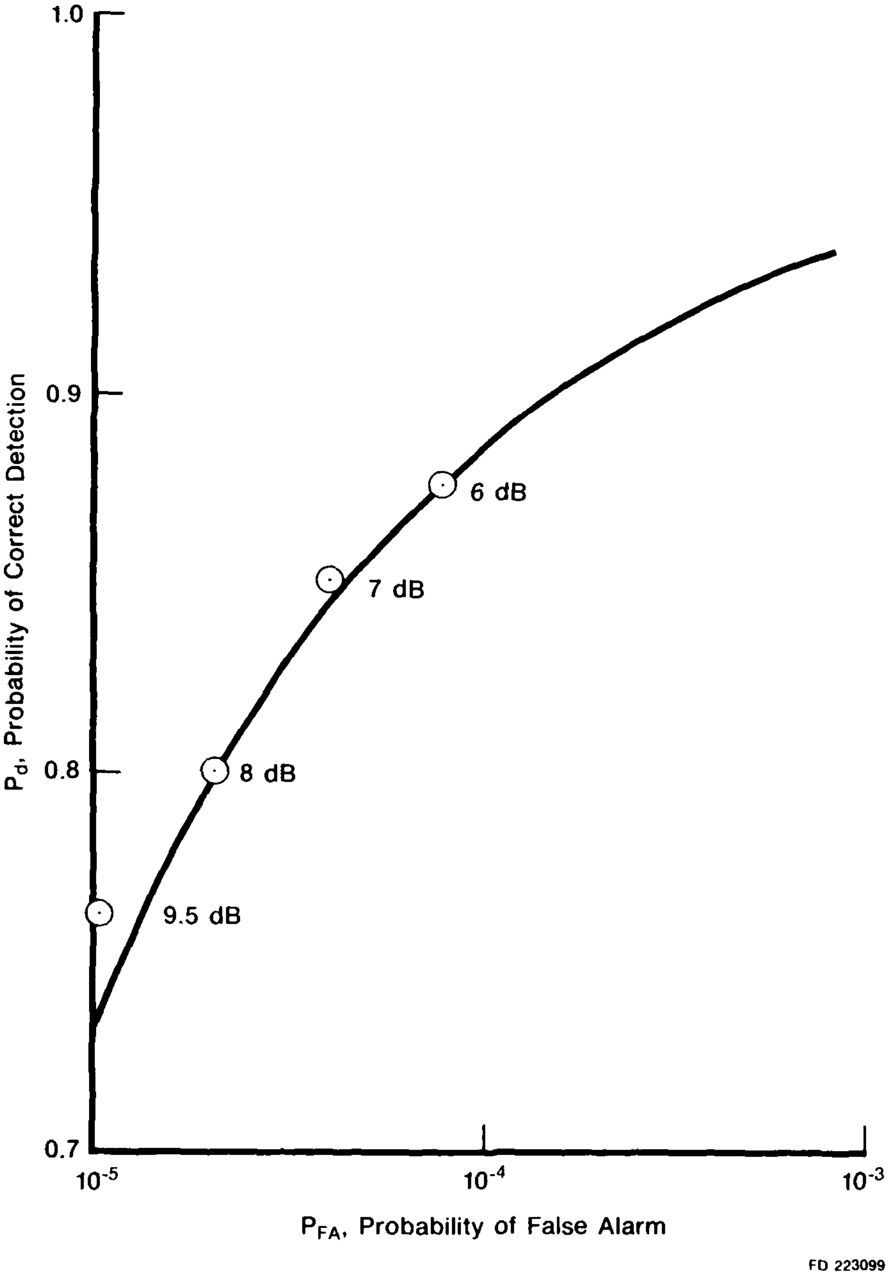

Figure J-4. Receiver Operating Characteristic Curve for In-Service Cracks. (Figure from Adaptronics, Inc.)

Based on these receiver operating characteristics, the expected performance of the Adaptronics instrument was computed in the report. Consider 10,000 disks, containing 100,000 boltholes of which 100 are cracked. The report predicted that 89 cracked holes would be correctly identified, 10 uncracked holes would be incorrectly rejected, and 11 cracked holes would be incorrectly accepted.

In evaluating the analysis in the Adaptronics report, the authors disagree with these numerical conclusions. In particular, we feel that the probability of false alarm per bolthole, rather than the probability of false alarm per detection opportunity, should be used in the analysis. Suppose the probability of false alarm per detection opportunity, as plotted in Figures J-3 and J-4, is 10^{-5}. The probability of false alarm per bolthole is 2,400 times this number (40 rotations/hole times 60 possible responses per rotation) or 2.4%. If this value is inserted in the analysis, the conclusion would be that 88 cracked holes would be correctly identified, 12 cracked holes would be incorrectly accepted, and 2,318 uncracked holes would be incorrectly rejected. As will be seen in the next section, this number is not inconsistent with the Failure Analysis Associates results.

It should also be noted that extrapolating these results to predict field performance depends upon the assumption that the distribution of flaw sizes is the same in the two cases. It is not likely that this would be the case, but evaluation of the numerical implications of the differences is beyond the scope of this report.

2.1.2 Failure Analysis Associates Conclusions

In the course of verifying the basic technologies and methodologies of RFC, Failure Analysis Associates (FAA) has assembled and analyzed eddy current inspection data on a large set of TF33 third-stage turbine disk boltholes. The sample base consisted of a 50-disk population, each of which contained 10 holes, for a total of 500 holes. These were examined in five independent inspections, using a variety of frequencies, instrumentation, procedures, and personnel.

Two field inspections were conducted at Tinker AFB using Gulton FD-100 units operating with a 0.50-in. dia coil at 500 kHz. The first was performed by field personnel while the second was conducted by laboratory personnel. Two additional laboratory inspections were conducted by Adaptronics, Inc. using Nortec NDT-15 instrumentation. These differed in frequency, one being at 0.5 MHz and the other at 1.0 MHz. The final inspection was performed by the Reluxtrol Corporation, using a Reluxtrol 700-29 CREG eddy current inspection system. The measurement frequency was 5 MHz, coil diameter was 0.040 in., and the probe advanced 0.0184 in. per revolution. The latter three tests were used as the data base for most of the analysis since the angular and axial positions of the probe were recorded in those cases, but not in the former two tests. This allowed a more complete comparison to the results of the replication studies.

All of the boltholes were replicated to determine the surface length of the cracks. In the 490 boltholes inspected, 847 cracks were found in 280 holes. Cracks ranged from less than 0.005 in. in length to 0.700 in. in length. Figure J-5 is a histogram of the crack lengths detected.

Twenty-eight of the boltholes were then destructively sectioned to characterize 56 of the crack indications. A considerable scatter in a plot of depth (from destructive testing) vs length (from replication) was observed, as shown in Figure J-6, with a crack aspect ratio of $a/c = 0.35$ providing an approximate fit. Whether this scatter represents error in the measurements or true scatter in the aspect ratio of the cracks cannot be fully known from the data presented in the report. The report appears to assume that it is the true scatter in crack aspect ratio that is being observed.

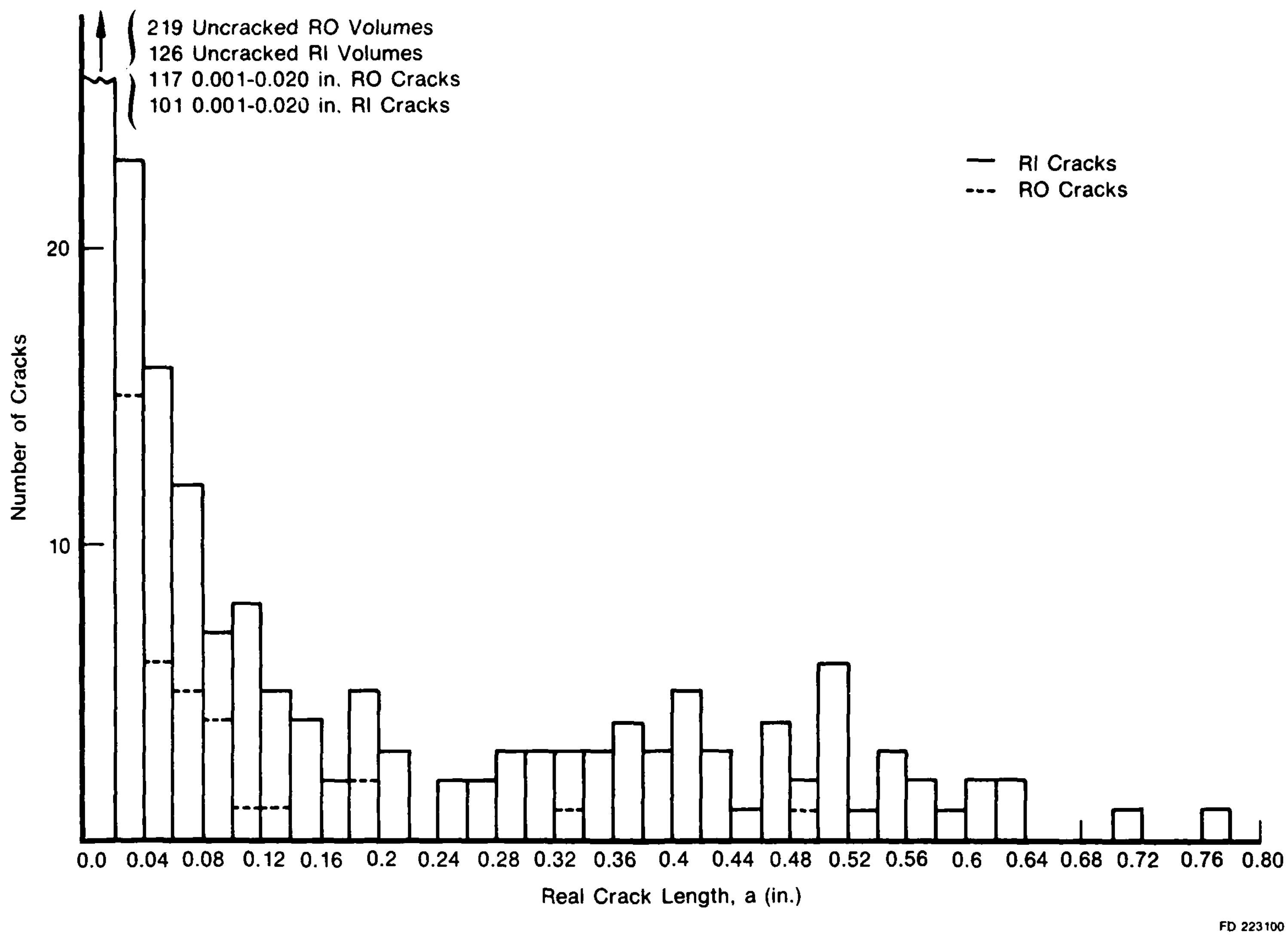

Figure J-5. Frequency Distribution of Real Crack Lengths (A) Determined from Surface Replication for the 1/2 Bolthole Volumes Inspected by the High Resolution Eddy Current System. The Symbols RI and RO Refer to the Inner and Outer Halves of the Boltholes, Respectively. (Figure from Failure Analysis Associates)

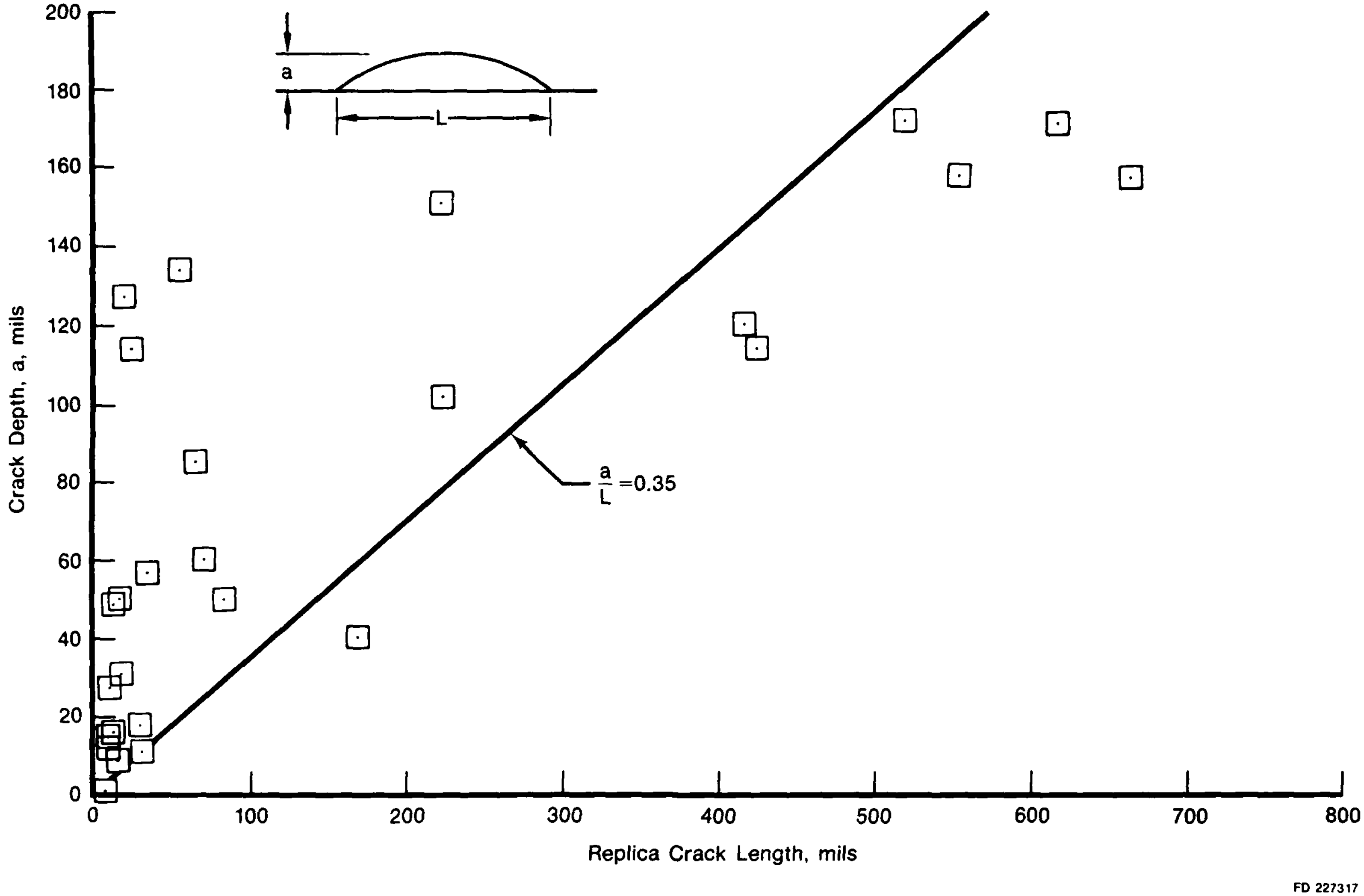

Figure J-6. Crack Depth vs Replica Surface Crack Length for ARPA Bolthole Cut-Ups Using the 0.040 Surface Crack Combining Criterion. (Figure from Failure Analysis Associates)

The results of the FAA eddy current evaluation are summarized in Figures J-7 to J-15. Figure J-7 presents Inspection Reliability and False Call Percentages for cracks greater than a given surface length. These results were computed on the basis of grading a call as correct if an indication was found in the same hole as a known crack, irregardless of any agreement between the magnitude and location of the indication and the size and location of the crack. For all cracks, the reliability ranged between 55 and 70% for all five inspectors, but rose to over 90% for cracks greater in length than 0.100 in. If, however, one requires that location (angular), length (to within a factor of 2), and axial position of the indication and actual crack all be in agreement, the results degrade to those shown in Figure J-8. Here reliabilities drop as low as 18% and false calls rise as high as 46% for all cracks.

The above probability of detection results may be somewhat conservative, since they are calculated on a crack population basis (i.e., each crack is considered as an opportunity for measurement, even if there are several cracks per bolthole). Higher probabilities can be expected on a bolthole population basis since there may be more opportunities to detect at least one of a set of multiple cracks. Figures J-9 and J-10 illustrate this for all cracks and cracks greater than 0.040 in. in length. Not shown in this figure is the false call probability. This will also rise on a bolthole population basis.

From the above plots, it can be concluded that the high resolution probe provided the highest reliability. Figure J-11 presents more details on its performance on a 1/2 bolthole population basis as a function of surface crack length and location agreement criteria.

The minimization of false rejects is essential if the full economic benefits of RFC are to be realized. This requires that an accurate sizing of the flaw be obtained from the nondestructive measurement technique. Figure J-12 illustrates the observed sizing performance of the high resolution probe. The apparent crack length is determined from the equation

$$\hat{a} = \left[1 - e^{-\frac{TURNS}{5.85}}\right]\left[2.38 \times 10^{-2}\,(TURNS)^{0.851} + 3.5 \times 10^{-2}\right] \tag{1}$$

$$+ \left[e^{-TURNS/5.85}\right]\left[2.48 \times 10^{-2}\,(AMP)^{1.187} + 6.59 \times 10^{-3}\right]$$

where TURNS is defined as the number of sequential turns, made by the coil, which produce an indication and AMP is the maximum amplitude of the indication. This empirical form was derived by performing a nonlinear regression analysis of the real crack length a, as determined from replication, vs TURNS and AMP.

From the scatter of the data in Figure J-12, it is clear that there was considerable uncertainty in the sizing. This was qualified by the inspection uncertainty function P(a/a). Figures J-13 to J-15 present plots of the cumulative distribution of a, i.e., the percentage of the time that the apparent crack length will be less than the size specified on the abscissa, for three different crack range intervals: 0.001 to 0.010 in., 0.040 to 0.060 in., and 0.100 to 0.700 in., respectively. In these ranges, the 90% point is reached at apparent to real crack length ratios of 9, 2.5, and 2.5, respectively.

This inspection uncertainty can strongly influence the economic benefits of RFC. This is illustrated in Figure J-16 in which the increase in economic gain per TF33 3rd stage turbine is shown when the inspection uncertainty is reduced by taking the square root of the size ratio. Such a reduction in sizing uncertainty is, of course, one of the major benefits of the quantitative NDE techniques to be discussed in Section 3.

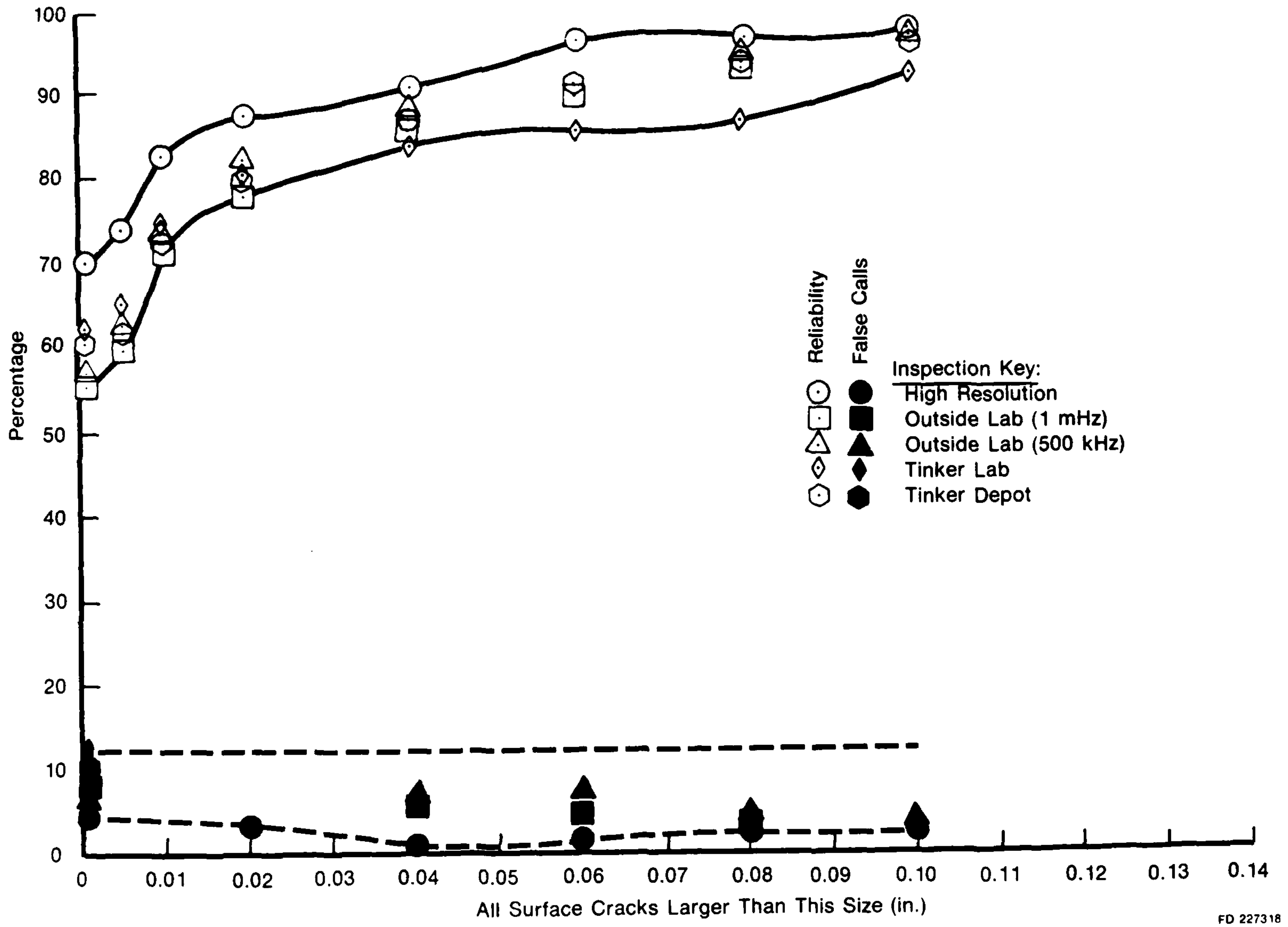

Figure J-7. *Inspection Reliability and False Call Percentages for Finding Cracks Greater than a Given Surface Length Using Only the Indication Agreement Criteria. (Figure from Failure Analysis Associates)*

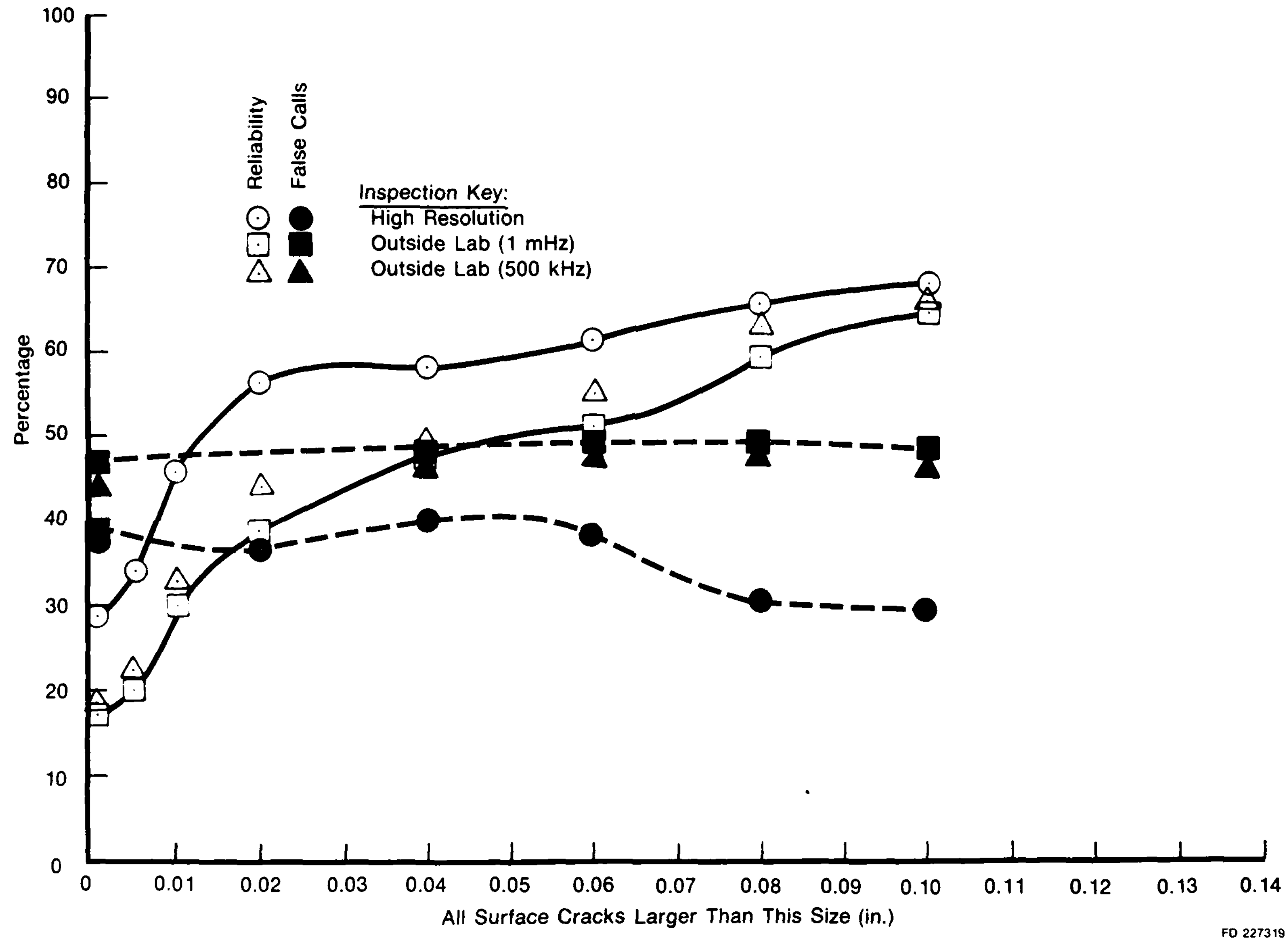

Figure J-8. Inspection Reliability and False Call Percentages for Finding Cracks Greater Than a Given Surface Length Using Indication and Location and Length (2X) and Position Agreement Criteria. (Figure from Failure Analysis Associates)

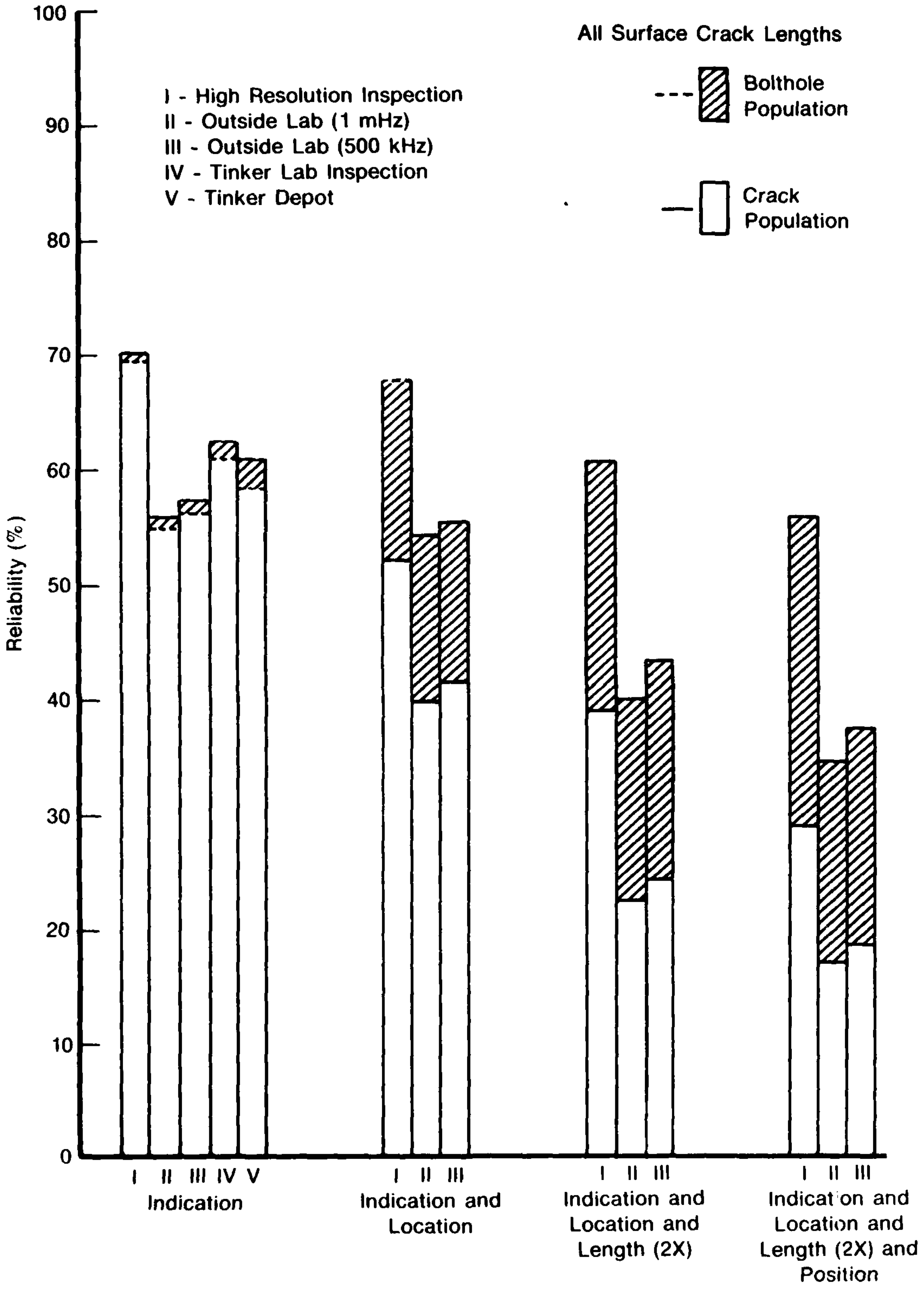

Figure J-9. Inspection Reliability of Detecting All Cracks as a Function of the Various Agreement Criteria. Open Bars Are for a Crack Population Basis and Shaded Bars Are for a Bolthole Population Basis. (Figure from Failure Analysis Associates)

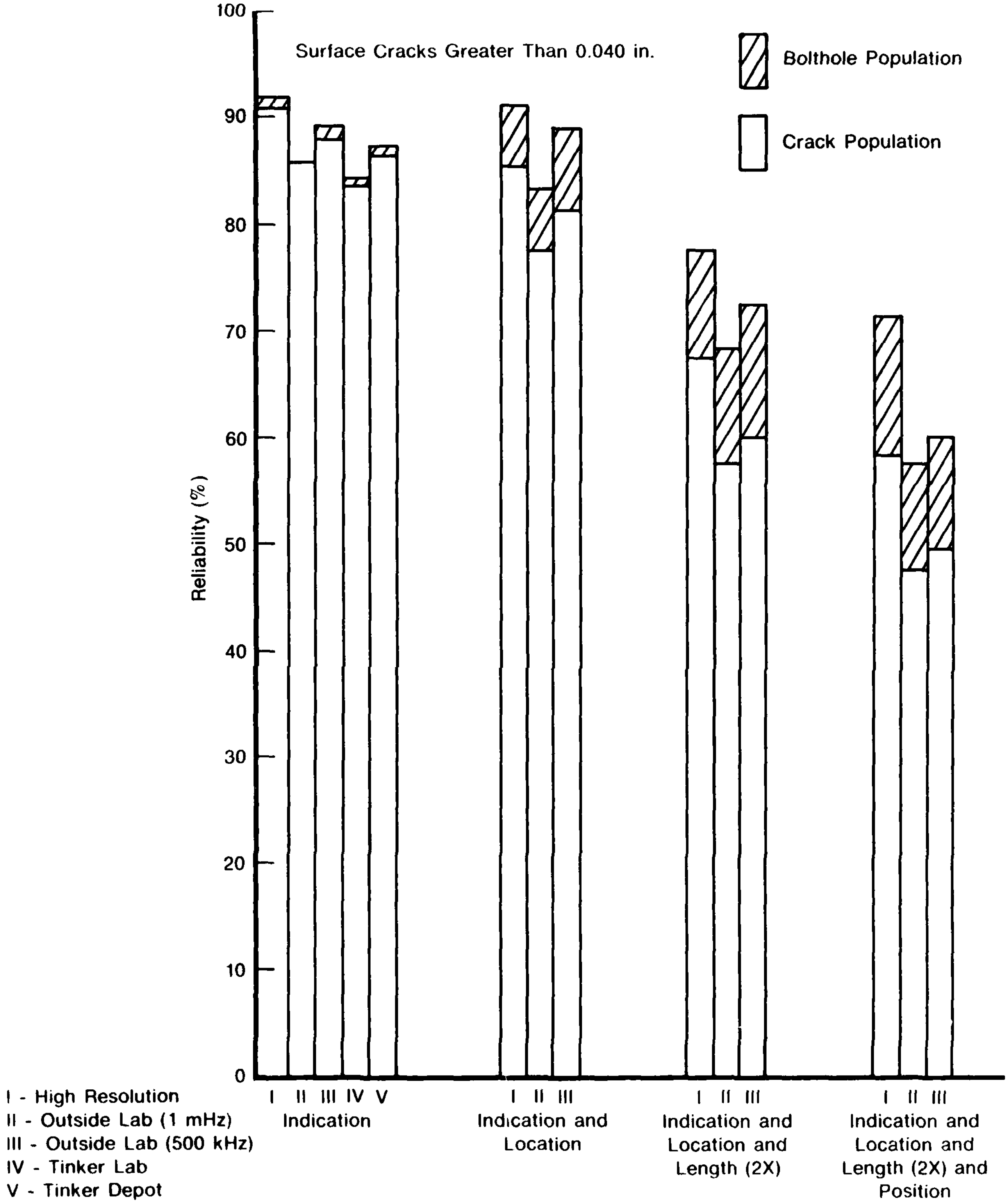

Figure J-10. Inspection Reliability of Detecting Cracks Greater Than 0.040 in. in Surface Length as a Function of the Various Agreement Criteria. Open Bars Are for a Crack Population Basis and Shaded Bars Are for a Bolthole Population Basis. (Figure from Failure Analysis Associates)

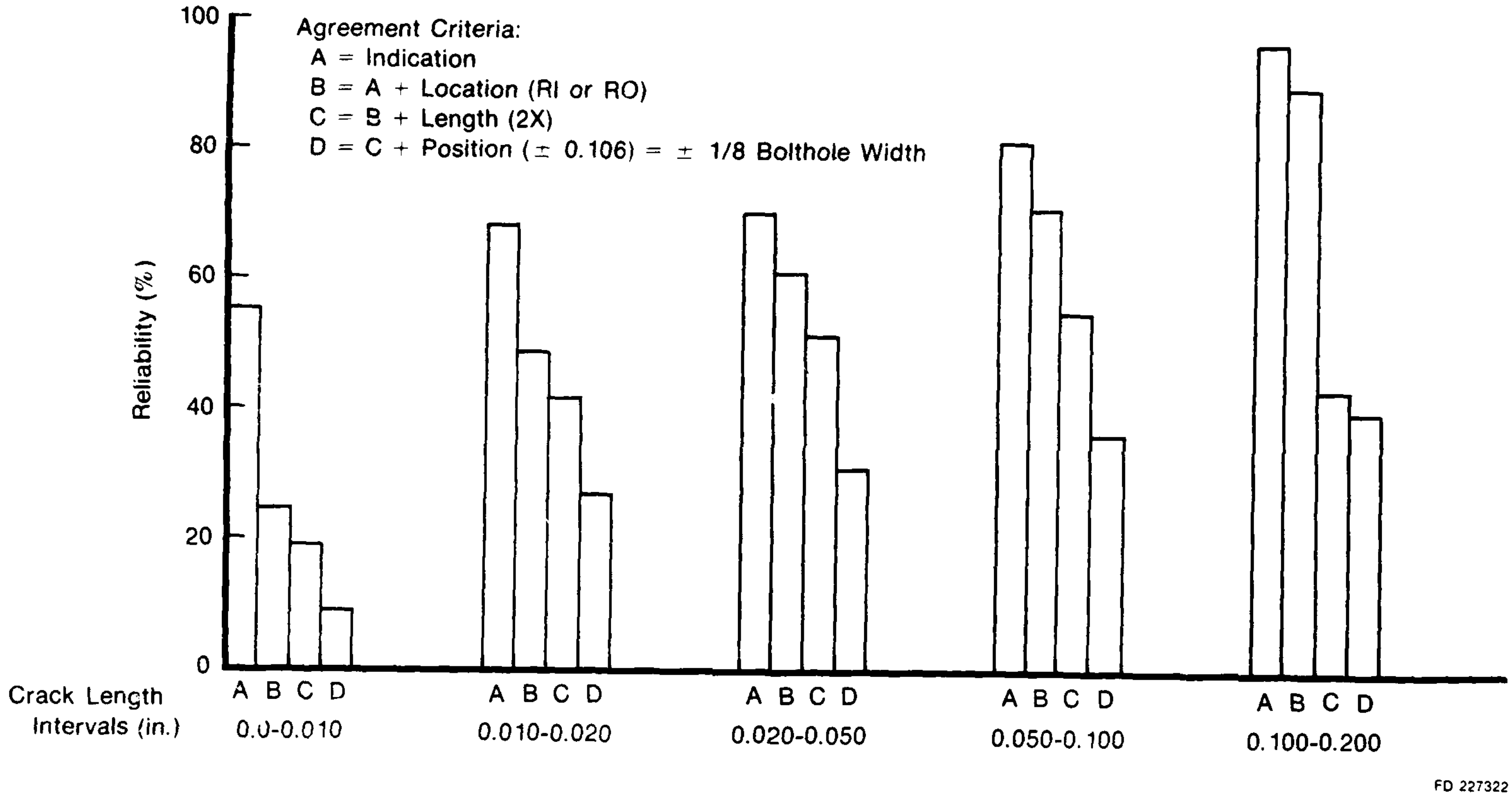

Figure J-11. Inspection Reliability for a Maximum Crack Within a 1/2 Bolthole Population for High Resolution Inspection as a Function of Various Agreement Criteria. Selected Surface Crack Length Intervals Are Indicated. (Figure from Failure Analysis Associates)

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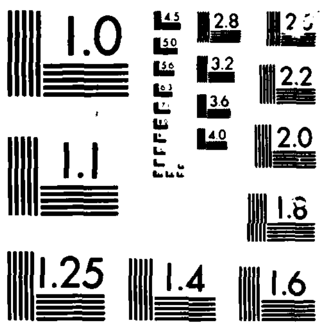

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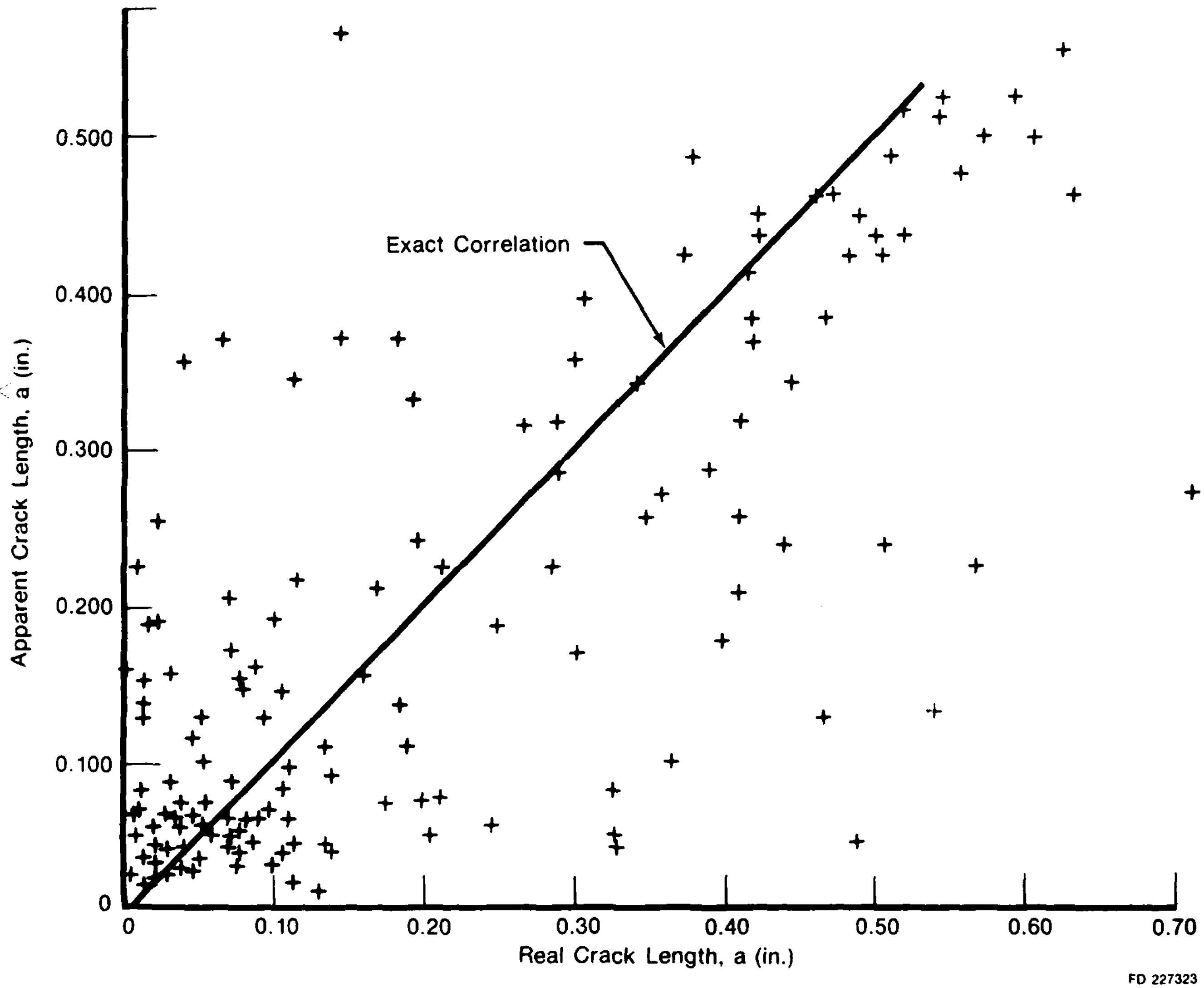

Figure J-12. Apparent Crack Length from High Resolution Inspection Signals vs Real Crack Length Measured by Replication. Equation 2 Was Used to Convert Eddy Current Inspection Results to Apparent Crack Length. (Figure from Failure Analysis Associates)

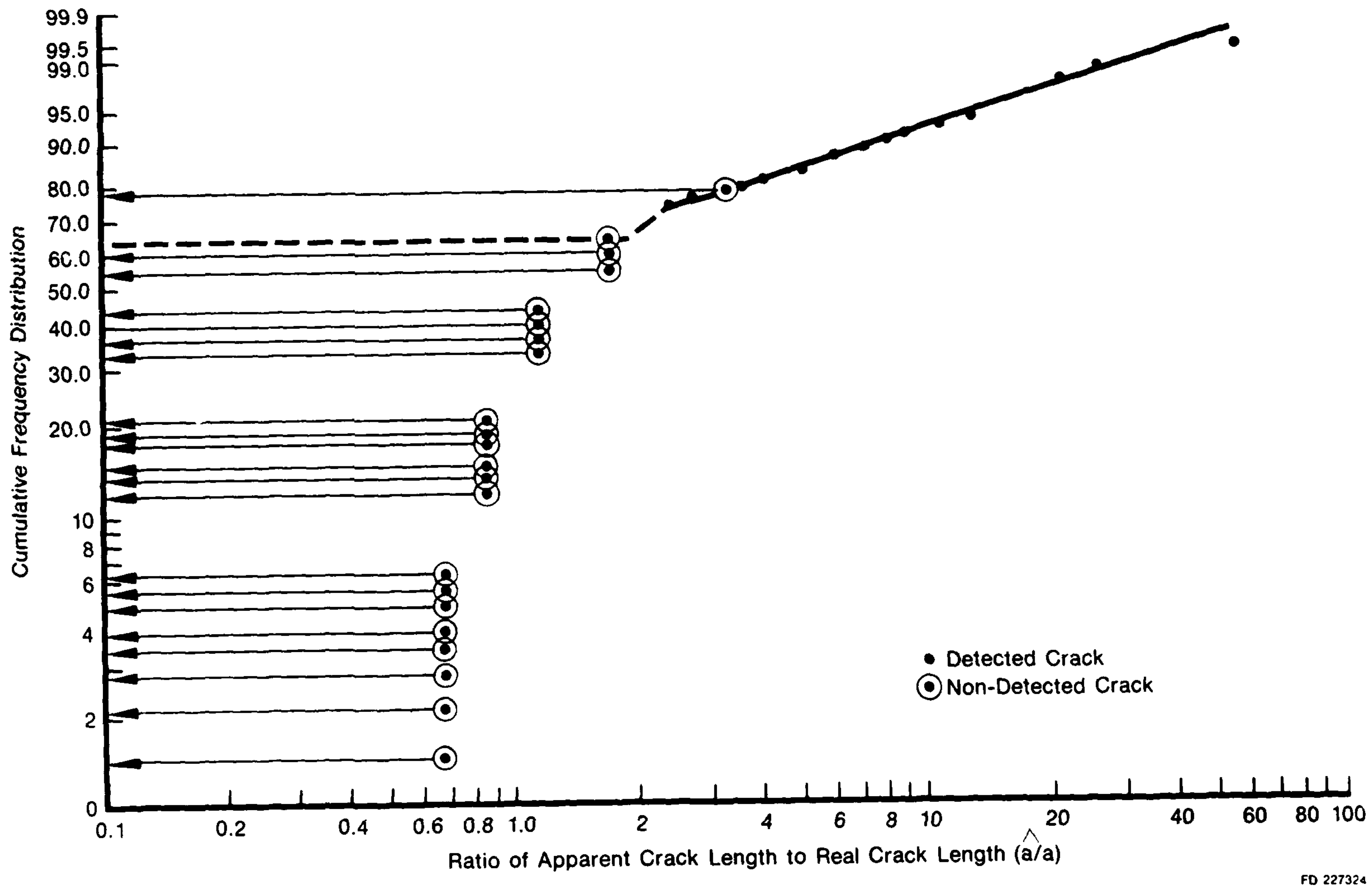

Figure J-13. Cumulative Frequency Distribution of Apparent Crack Length to Real Crack Length for High Resolution Inspection. For Clarity Not All Points Have Been Plotted, Only a Representative Sample. Real Crack Length Range: 0.001-0.010 in. (Figure from Failure Analysis Associates)

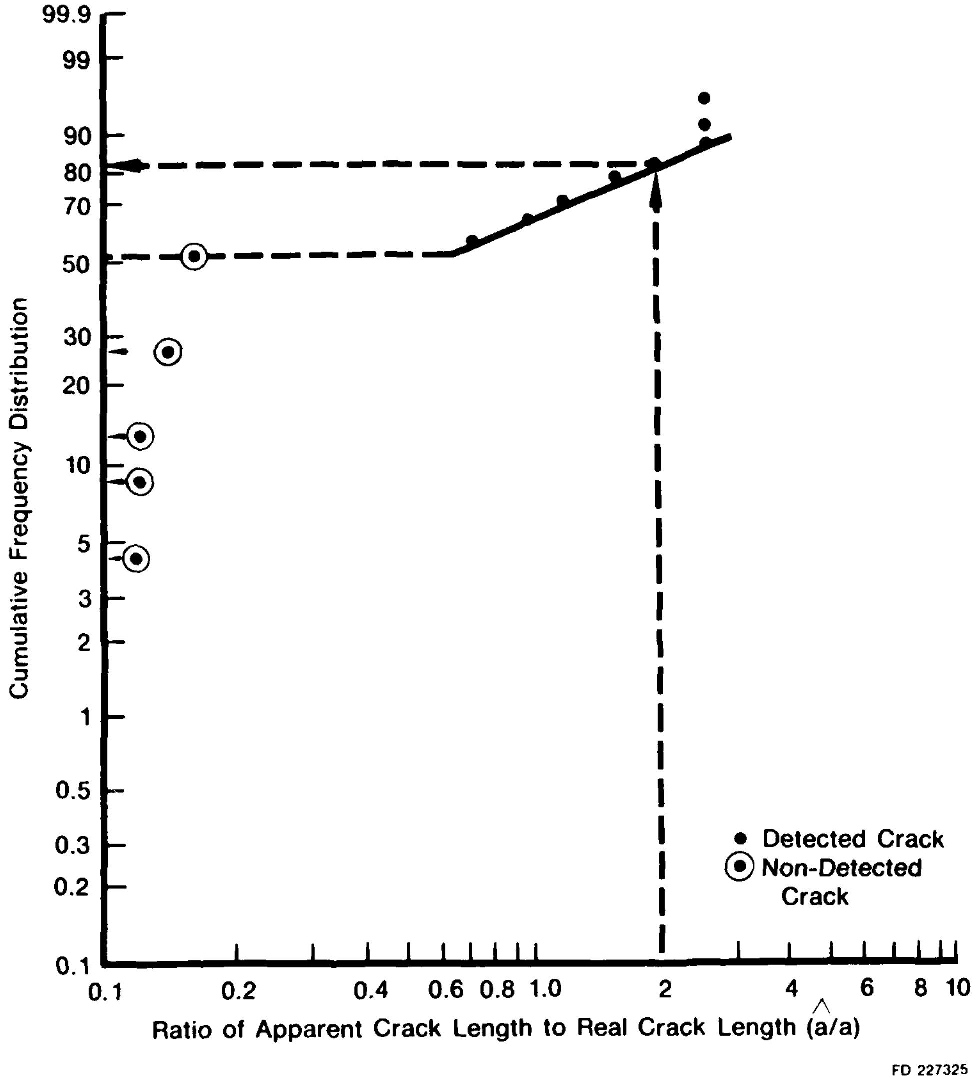

Figure J-14. Cumulative Frequency Distribution of Apparent Crack Length to Real Crack Length for High Resolution Inspection. Real Crack Length Range: 0.040-0.060 in. (Figure from Failure Analysis Associates)

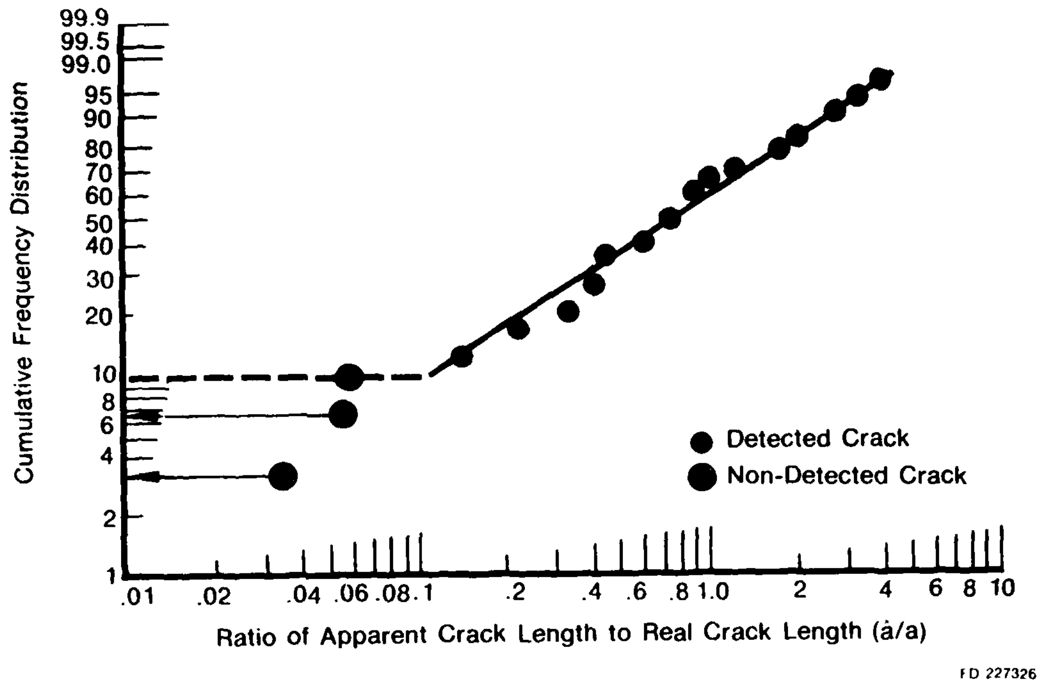

Figure J-15. Cumulative Frequency Distribution of Apparent Crack Length to Real Crack Length for High Resolution Inspection. Real Crack Length Range: 0.100-0.200 in. (Figure from Failure Analysis Associates)

2.1.3 Summary of Present Eddy Current Capability

In summary, the sensitivity of conventional eddy current is probably adequate to detect cracks 0.005 in. or less in length. For sizes on the order of 0.040 in. or greater, reliability of detection, on a bolthole basis, can be on the order of 90%. This will be accompanied by a significant probability of false calls. However, for smaller flaws, on the order of 0.005 in. or less, such as may be of interest in application of RFC principles to such engines as the F100, reliability of the present eddy current techniques drops to 50% or less. In addition, there may be a significant problem with false rejects, as illustrated by the following discussion.

Suppose first that one wishes to reject all flaws greater than 0.005 in. and the instrument is set up so that rejection occurs when the apparent flaw size is greater than this value. Then from Figure J-13, approximately 50% of real 0.005 in. flaws would have apparent size less than this value and would be falsely accepted. Fortunately, as noted in the FAA report, the evolution of failure is such that, in a given disk, there are likely to be several cracks of approximately the same size since all boltholes have experienced virtually identical fatigue histories. Consequently, although any particular crack would only be rejected 50% of the time, the probability of rejecting at least one would be considerably higher. Unfortunately, this same reasoning refers to false rejects. Thus, a single 0.001-in. flaw would have an apparent size greater than the 0.005 in. threshold 15% of the time, and if there are several of these, the probabilities are much greater. A high false reject level might ensue. The trade-off between false accepts and false rejects appears to be quite difficult.

It should be emphasized that these comments are quite speculative since (a) they are making extrapolations to quite small flaw sizes from data obtained on a system designed to detect larger flaws, and (b) they are not based on a full statistical argument such as is contained in the FAA report for the TF33 disk with larger critical flaws. Nevertheless, they do suggest that care should be taken when relying on the state of the art to detect crack sizes on the order of 0.005 in., and that quantitative NDE techniques with better sizing ability may be essential if the economic potential of RFC is to be realized in materials having critical sizes in this range.

2.2 Ultrasonic Inspection

As shown in Figure J-2, the great majority of the generic flaw types are surface connected due to the low cycle fatigue origin of the failure. These are most amenable to eddy current inspection. However, a few examples of internal flaws are also given, including cracks in the web and inner bore of the turbine. Hence, ultrasonics will be required and an assessment of the state of the art of that technology is appropriate.

Unfortunately, no programs similar to the above mentioned eddy current efforts have been run for the case of ultrasonic inspection of turbine disks. Consequently, the assessment is less accurate and must be based on extrapolation from experiences in related programs.

A few bench marks can quickly be established. The sensitivity of ultrasound is certainly adequate to detect crack-like flaws with sizes on the order of 0.005 in. or less if (a) the attenuation and gain scattering noise of the material are sufficiently low that high frequencies can be used, and (b) the geometry and flaw orientations are such that a pulse-echo or pitch-catch configuration can be defined which detects the specular reflection from the crack surface. According to the criteria that the wavelength should be on the order of the flaw size for maximum sensitivity, this implies the need for frequencies on the order of 50 MHz for which the wavelength is approximately 0.004 in. However, as discussed in the next section, the use of considerably lower frequencies may be possible.

The question of reliability is somewhat more difficult. It can be speculated that, because of the known influences of crack closure stresses and crack orientations on state-of-the-art ultrasonics, the reliability of present day equipment will be somewhat less than that for eddy currents. Advances on the state of the art of ultrasonics may bring greater improvements in detection reliability in appropriate application areas than advances in eddy current technology.

3. POTENTIAL OFFERED BY ADVANCED METHODS FOR QUANTITATIVE NDE

3.1 Criteria for Technique Selection

The low reliability that has been observed with state-of-the-art techniques for the small crack sizes likely to be of interest in rotor components of the F100 engine suggests that substantial improvements will be needed if high probabilities of flaw detection are to accompanied by acceptably low false reject rates. In particular, and as illustrated in Figure J-16, it appears quite advantageous, and perhaps essential, to improve flaw sizing capabilities so that parts with detectable flaws can be returned to service if the flaw is sufficiently small. The purpose of this section is to review those techniques which hold the promise of being able to impact this problem area in the near or intermediate term. Section 4, which follows, provides guidelines for proposed programs that would bring the technologies to a sufficient level of development that they then could be incorporated in an automatic system for RFC of turbine engine rotor components.

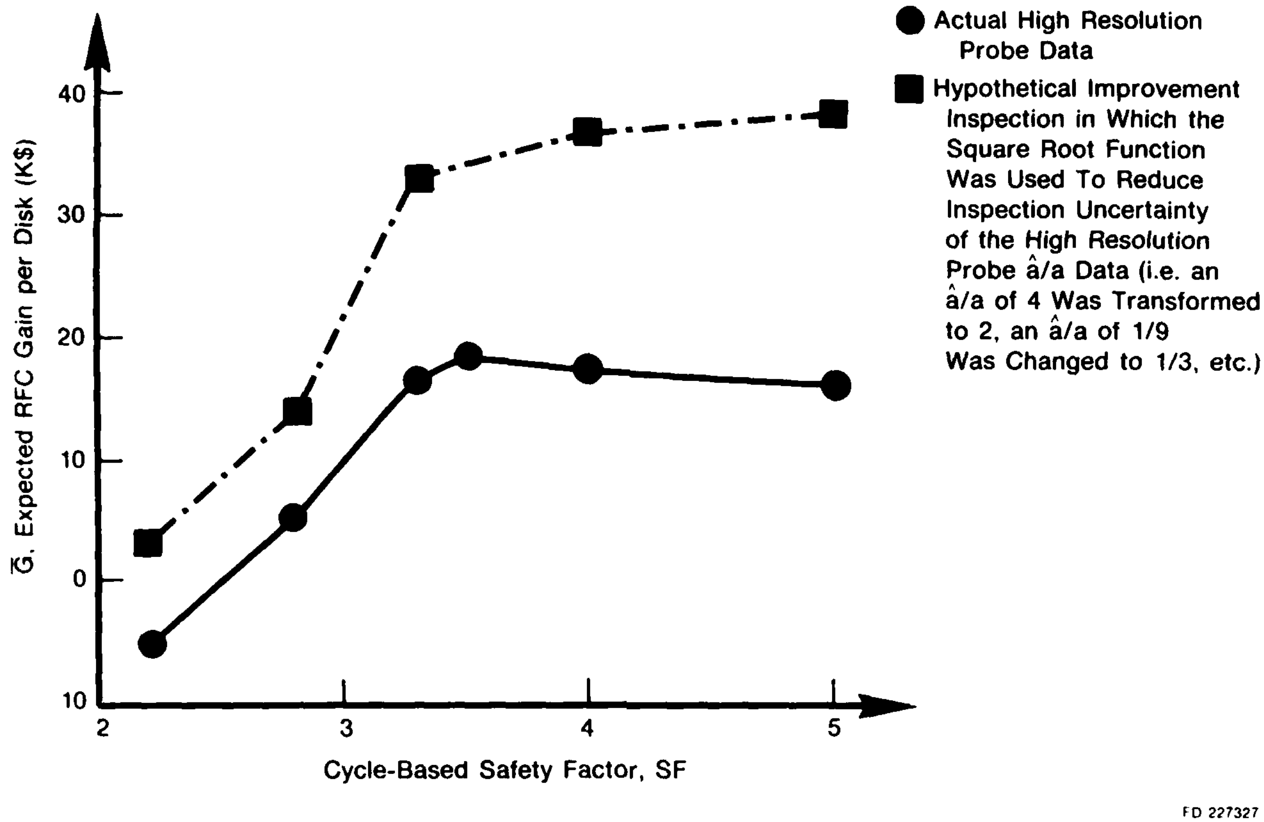

Figure J-16. Effect of a Dramatic Reduction of Inspection Uncertainty on RFC Benefits. (Figure from Failure Analysis Associates)

More specifically, the following criteria have been adopted in screening techniques and recommending programs. First, only generic rotor components and flaw types are considered, as represented by the composite sketches in Figures J-1 and J-2. Specific critical flaw sizes are not addressed, since these depend upon a number of factors which have not been fully defined, and/or are not known to the authors at this time, and since these sizes will vary from engine to engine and component to component. It is, however, recognized that relatively small flaws are likely to be of concern in components of the F100 engine, which is of high current interest, and particular attention is placed on the small flaw end of the flaw distribution.

In making the assessment, it is anticipated that an automatic NDE system for inspecting rotor components will be constructed and tested at an Air Force Logistics Command Maintenance Depot in the 1984-1985 time frame, as it is presently in a procurement process through the Air Force Wright Aeronautical Laboratory. A technique could impact that system in one of two ways. First, it could be fully evaluated at the present and therefore be ready for direct incorporation in the system. Second, it could be sufficiently well developed that hardware modules could be available in the 1983-1984 time frame for incorporating in, or testing in parallel with, the automatic system. In the latter case, 6.2 development programs should be nearing completion for the candidate technique and the initiation of 7.8 manufacturing

technology programs should be contemplated in the near future. In other cases, new techniques are progressing rapidly, but may not be quite ready in that time frame. These fall into a third category of techniques which may be available for incorporation in a second generation RFC system. They are discussed in this report for completeness. The present Section 3. discusses the potential offered by the candidate advanced techniques and identifies remaining technical questions that need to be answered before they can be used with full confidence. Section 4. then presents specific programs that could be initiated to develop these techniques to the level required to realize these potentials.

Before turning to the specific techniques, it is worthwhile to briefly review the physical reasoning behind the selection of particular forms of energy to be used in detecting and characterizing flaws. Table J-4 lists the four types of flaws that are expected and six candidate types of interrogating energy. Also included are the authors' opinion regarding the applicability of the types of energy to detecting and sizing the flaws. An entry of D implies that, based on the physical principles involved, the technique should be of high utility in detecting flaws of the particular type indicated. Entries of C and A indicate a strong potential for measuring length and depth, respectively, for surface cracks and for measuring the dimensions parallel to and perpendicular to the web surface, respectively, for internal cracks. In a number of cases, lower case letters are used. This indicates that the technique has potential, but it is deemed to be of less immediate utility either because of complicating physical factors or a lower degree of development.

The Table indicates that eddy currents are quite effective for detecting surface flaws, and provide important sizing information. These are discussed in greater detail in the remainder of the section.

TABLE J-4. CANDIDATE NDE TECHNIQUES FOR FLAWS IN ROTOR COMPONENTS

	Eddy Current	*Ultrasonics*	*Penetrants*	*X-Ray*	*Optics*	*Thermal Waves (photoacoustics)*
Internal flaws		D C,A		d c		
Through flaws (knife edge seal	D C,A	d c,a	D C	d c	d c	d c,a
Corner flaws	D C,A	d c,a	D C	d c	d c,a	d c,a
Surface flaws	D C,A	d c,a	D C	d a	d c	d c,a
Code:	Detection	Sizing				
Higher potential	D	C,A				
Lower potential	d	c,a				

Ultrasonics is the preferred technique for detecting and sizing internal flaws. Specific approaches will also be discussed later in this section. Ultrasonics can be used, in principle, for surface connected flaws. However, the complex geometries of rotor components makes this quite difficult, and it is judged to be a low priority approach for such flaws.

Penetrants are quite useful in detecting surface cracks. However, since they provide only one size parameter, since they sometimes experience reproducibility problems, and since there is little effort being devoted to quantifying their output, they are not discussed further. This does not imply that they should not be incorporated in an RFC system, only that they are not judged to have a high potential for sizing.

X-rays have detection and sizing potential, but this is practically limited by (1) the fact that the reliability of detecting cracks (rather than volumetric flaws) is low, and by (2) the capabilities of available instrumentation. A brief review of some of the more advanced instrumentation that is presently available, or under development, is given.

Optical techniques have promise for detecting and measuring surface lengths of cracks where sufficiently clean surfaces can be achieved. A program is underway at the Rockwell International Science Center to evaluate this potential for RFC application, and some preliminary results are described.

Thermal waves are a relatively untested form of probing energy which can be excited by modulated laser or electron beams which periodically heat and cool a surface which they strike. They can be detected by a variety of means, including acoustic waves radiated by the expansion of the surface and infrared temperature monitoring. Flaws are indicated by changes in these responses to the thermal excitation. Thermal waves have many properties similar to those of eddy currents, in that they satisfy a diffusion equation and are excited and detected at the surface. They should ultimately find important applications in both metals and ceramics. However, development is in a fairly early stage. Thermal waves clearly fall in the third category of techniques to be considered for a second generation system.

3.2 Eddy Currents

The NDE of F100 engine components, for the purposes of RFC, strongly points towards eddy current (EC) techniques for surface flaw inspection. In assessing the potential that advanced methods of EC inspection offer to quantitative NDE, this section will start with a brief technical review of the EC method in order to put candidate systems in proper perspective with the inspection problems. Next we will review in general: presently available systems, systems under development, new systems and analytical techniques.

3.2.1 Review of Eddy Current Principles

There are basically two kinds of EC systems: the first, and most widely employed, measures the change in impedance of a search coil due to the presence of a flaw and thereby infers something about the flaw. The second method measures the spatial distribution of the perturbed fields caused by the flaw and attempts to infer something about the nature of the flaw through an inversion process.

The case of a search coil terminated in a pair of wires may be viewed as a hybrid lumped element and distributed system, Figure J-17. Here the wires constitute the lumped element system and the field volume constitutes the distributed system. At the terminal pair of the coil, the complex input circuit power P is given by

$$P_{in} \quad \int P \cdot ds \quad j\omega\,(W_H + W_E) + PR \tag{2}$$

where $P \quad E \times H$ Poynting Vector (3)

$$W_B = \frac{\mu}{2}\int H^2 dv \quad \text{Stored energy: magnetic field} \tag{4a}$$

$$W_E = \frac{\epsilon}{2}\int E^2 dv \quad \text{Stored energy: electric field} \tag{4b}$$

$$PR = \sigma \int E^2 dv \quad \text{Dissipated power} \tag{4c}$$

and μ is the magnetic permeability, ϵ is the dielectric constant, σ is the electric conductivity, H is the magnetic field, E is the electric field, ds is a surface element and dv is a volume element.

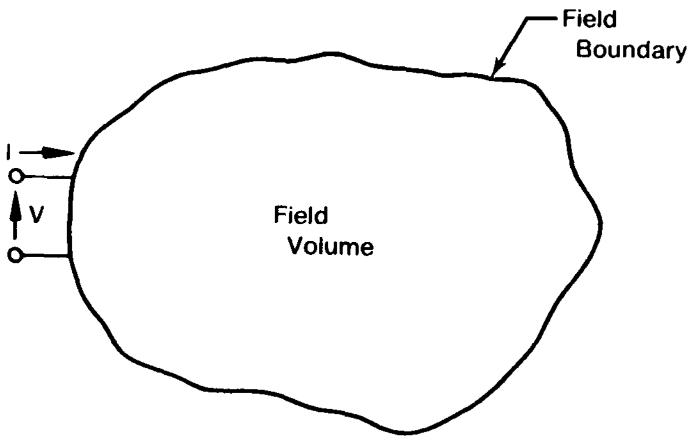

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Figure J-17. Eddy Current Detection Model

Here the real part of the input power P corresponds to the time average power dissipation whereas the imaginary (reactive) part corresponds to energy storage. The related circuit power is given by

$$P_{in} = VI$$

and the equivalent lumped element circuit quantities are given by

$$L = \frac{\mu}{I^2}\int H^2 dv \quad \text{inductance} \tag{5a}$$

$$C = \frac{\epsilon}{V^2}\int H^2 dv \quad \text{capacitance} \tag{5b}$$

$$R = \frac{\sigma}{I^2}\int H^2 dv \quad \text{resistance} \tag{5c}$$

Within good conductors there is virtually no displacement current so the capacitance is negligible.

The change in L, ΔL, due to the flaw is given by

$$\Delta L = \frac{2\mu}{I^2}\int_{vol} H_0 \cdot \Delta H dv \tag{6a}$$

and similarly for R

$$\Delta R = \frac{2\sigma}{I^2}\int_{vol} E_o \cdot \Delta E dv \tag{6b}$$

where H_o, E_o are the fields without flaw and ΔH, ΔE are the field changes due to the flaw. Here terms on the order of ΔH^2 and ΔE^2 have been dropped in the respective integrands. Note that E and H are indirectly related through Ampere's Law.

The key feature of the above derivation is the fact that the impedance change ΔZ is the result of an integration over a volume and, further, that the volume need be no larger than the extent of the perturbed fields near the flaw. In particular, the required integration volume is not directly dependent on the coil size. The change in impedance strongly depends on the coil size, however, since a coil that is large compared to the flaw region will have weaker H_o fields for a given current than a small coil. The field perturbation ΔH is proportional to H_o and so a weakening of H_o by a poor coil geometry reduces ΔL by the square of this weakening. Thus, the size of a search coil is expected to strongly influence the sensitivity of the system to small flaws which give rise to localized perturbed fields.

The field volume over which the integration takes place is determined by the diffusion spreading of the EC fields as well as the coil geometry. (Recall that electromagnetic fields in a good conductor satisfy the diffusion equation.) If a coil diameter is large compared to the electromagnetic skin depth, δ, the transverse extent of the fields is largely determined by the coil geometry. A coil with diameter less than δ has a diffusion controlled field profile. The depth of the field is approximately δ in each case. The ratio of flaw field volume to coil field volume is a measure of the coil sensitivity, given to a first order approximation by

$$V \simeq \frac{(\ell+2\delta)\ (w+2\delta)\ (d+2\delta)}{(D+2\delta)^2\ (\delta)};\ (\ell + 2\delta) < D \tag{7}$$

where ℓ, w, d are the length, width and depth of the flaw and where D is the diameter of the circular coil. If the flaw is a crack, $w \simeq 0$, and if the crack is longer than the coil diameter, $\ell + 2\delta > D$, then the volume fraction is given by

$$V \sim 2\left(\frac{d+2\delta}{D+2\delta}\right);\ (\ell + 2\delta > D) \tag{8}$$

Clearly, in this case, the length of the crack has no effect on ΔZ as expected. The sensitivity is increased if D is decreased but is eventually limited by diffusion. If the crack depth is small then δ must be decreased (increase in frequency) as well as D in order to keep V sensitive to changes in d.

Using this simple picture it is possible to characterize an EC system as operating in one of four conditions, Table J-5. In interpreting the table, one should consider the dimensions of the flaw to be detected as fixed. One can select a frequency such that the diffusion volume, δ^3, is less than or comparable to this volume. Similarly, one can design the probe to have a field volume comparable to, or greater than, the flaw volume. The general characteristics of the four possible combinations of these conditions are indicated in the table. It is of interest to note that the greatest sensitivity to flaw dimensions occurs when all three volumes are comparable. Unfortunately, this may imply a very small coil size, and coil arrays or other instrumentation advances may be required to achieve adequate scanning speeds.

TABLE J-5. PROBE-FLAW CATEGORIES

	Large Probe $\frac{\text{Field vol}}{\text{Flaw vol}}$ 1	*Small Probe* $\frac{\text{Field vol}}{\text{Flaw vol}}$ 1
Large flaw $\frac{\text{Flaw vol}}{\delta^3}$ 1	I Length uncertain if crack much less than coil diameter Depth uncertain	II Depth information less certain Good transverse resolution Most absolute impedance change
Small flaw $\frac{\text{Flaw vol}}{\delta^3}$ 1	III Least absolute impedance change	IV Most sensitive to transverse and depth dimensions

3.2.2 Discussion of Presently Available Systems

In the work discussed in Section 2, most probes were large and the frequencies low resulting in condition III. The Reluxtrol probe operating at 5 MHz (δ=0.01 in.) with 0.040-in. coil diameter was almost a "small probe" and was in condition II or IV depending on the crack size. This instrument was most reliable for cracks longer than 0.040 in., condition IV, and was less accurate in condition II when the flaw sizes become of the order δ.

For the NDE of F100 engine components where 0.005-in. flaws may need to be detected reliably, a coil system in condition IV would be desirable implying a 0.005-0.010-in.-dia field at 20 MHz. Having the proper coil is only part of the requirements; adequate instrumentation with signal processing will also be required.

Some of the older systems in current use, such as those discussed in Section 2, employ coil sizes or coil geometries that were not intended for use with such small flaw sizes. Consequently, a greater uncertainty in flaw sizing is to be expected in these cases.

3.2.3 New Approaches Based on Measurements of Probe Impedance Change

Recent research has been directed towards seeking means to decrease coil size and/or skin depth and thereby enter the more favorable regimes of operation. Research activities at Stanford University and SRI International have demonstrated the utility of microwave approaches in this regard. Recently initiated 6.2 development programs are pursuing these concepts further. The programs are in too early a stage to have produced results which are reportable here.

Of these approaches, the YIG resonant sphere appears to hold particular promise for turbine component NDE since it consists of a compact structure. In particular, the YIG resonant sphere probe operates at 1GHz where the skin depth is only a few microns in F100 component alloys. It can have sizes on the order of 0.010 in., which is nearly ideal based on the above analysis. A full assessment of this system cannot be made at this time because the aforementioned development program is still in progress. The early research has established that large impedance changes are produced when such a probe interrogates a crack. A major question that remains regards the sensitivity of bridge circuitry at these high frequencies. One would expect bridge performance to be poorer, and it must be established that this does not offset the increased impedance changes. Tasks in the DARPA/AFML Interdisciplinary Program for Quantitative NDE, as well as the above mentioned development program, should provide substantive answers by the end of FY81.

One danger exists in operating an EC system at such high frequencies. The skin depth can become so small that only surface breaking cracks are detected. This presents a potential problem in two distinct cases. First, metal smearing of only 5 m will significantly obscure the true nature of a flaw at 1GHz. Moreover, such effects as metal smearing and oxides in the crack, which affect microwave eddy currents, can cause the measurement to indicate that the crack is really much smaller than its true size. The importance of these effects depends critically upon the condition of the inner hole surface at the time of inspection. Since the same problems cause difficulties for penetrant inspections, it is possible that surface etching or cleaning steps will be implemented which will eliminate this difficulty. The second case regards subsurface flaws. For example, some of the low frequency measurements reported in Section 2 were able to detect near subsurface flaws which were subsequently confirmed by destructive tests. These are important precursors to surface breaking cracks, and, depending on the details of the RFC strategy, their detection may be crucial. They would have gone undetected if only a microwave frequency technique had been used. Consequently, the use of multiple frequencies, or a frequency agile system, may be needed to achieve high sensitivity to small surface breaking cracks as well as adequate sensitivity to near-surface cracks.

Another new approach to the interpretation of eddy current signals obtained with a single probe system has been proposed by Auld of Stanford.[2] In considering the regime $a/\delta \ll 1$ (a is the flaw radius) and coil size $\gg$ flaw size (implied by the uniform interrogating current assumed in his analysis), Auld develops an absolute relationship between the stress intensity factor of a flaw and the change in impedance of a coil. This follows in direct analogy to similar relationships that were previously demonstrated for the case of ultrasonics which are discussed in the next section. This result may have important implication in flaw sizing, and hence in reducing state-of-the-art accept/reject errors discussed in Section 4. However, the assumptions used in the analysis place the technique in category III of Table J-5, and sensitivity problems may be encountered in practical applications.

3.2.4 New Eddy Current Systems Based on Field Mapping

New approaches to EC flaw characterization have been under development at Northrop under corporate IR&D and AFML funding. Based on some of the ideas presented in Section 1, small coils tightly coupled to the metal surface have exhibited 8 to 10% impedance changes while detecting fatigue cracks. When such large changes occur, bridge circuits may not be required.

Arrays of small coils have also been demonstrated. These may make it possible to combine the sensitivity of small probes with the high scan rates required in practice. They may also be configured in a way to provide more accurate sizing information. In the AFML PPG program, "Improved Low Frequency Eddy Current Inspection for Cracks Under Installed Fasteners," a new approach to EC detection employs an array of sensor coils to measure the

spatial pattern of the EC fields and to detect variations in the field profile due to second surface cracks. The system can detect field variations as low as 10 ppm. One-tenth inch cracks in the second layer (beneath 1/4 in. or more of aluminum) produce changes in the 100 ppm range and are easily detected. To avoid the lift-off problem, the system uses electronic rather than mechanical scanning.

Another new approach, called the electric current perturbation technique, has been under development at Southwest Research Institute. In this case, the technique has been applied to the problem of detecting fatigue cracks in TF33 turbine disks. Isolated cracks as small as 0.012-in. long and 0.005-in. deep have been detected, as have distributions of smaller cracks.[1] The technique consists of injecting a current into the part under inspection, either by direct ohmic contact or inductively via an adjacent coil driven by a time varying current. The presence of a crack interrupts the flow of current in the part surface and the magnetic flux which "leaks" out of the part can be detected by a suitable sensor based on inductive or solid state principles. From this point of view, the technique can be considered as an extension of magnetic flux leakage principles to nonmagnetic materials.

However, the technique can be equally well thought of as an advanced eddy current technique. As noted in subsection 1, there are two kinds of eddy current systems: those measuring the changes in impedance of a search coil, and those measuring the spatial distribution of the field perturbation caused by the flaw. The electric current perturbation technique is an example of the latter which appears to have considerable promise for RFC applications.

3.2.5 Analytical Techniques for System Design and Evaluation

In the development and application of EC systems to the RFC problem, it will be necessary to develop adequate mathematical tools for predicting system performance. This will be useful in both system design, where such questions as "how large should the coil be?" must be answered, and in estimating the reliability of detection for the particular configuration selected.

At the present time, a coordinated effort involving Stanford Research Institute, Stanford University, and General Electric, is moving towards such a capability. By way of a brief (and oversimplified) summary, the effects of flaws on probe impedances are being analytically studied at Stanford (with field strength as a parameter). This field strength is being calculated at General Electric using finite element techniques, and the ability of bridge circuits to detect the resulting coil impedance changes are being modeled at Stanford Research Institute. It is anticipated that numerical results for the case of a half-penney shaped crack, detected by a circular coil, will be presented at the 1981 Review of Quantitative NDE to be held in Boulder, Colorado on August 2-7.

In this present approach, the finite element analysis of the coil in a flaw free region of the material is combined with perturbation analysis of the flaw induced changes in these fields to predict absolute impedance changes when the coil size is large with respect to the flaw. Thus the finite element calculation need only be done once to establish the fields of the coil and then the flaw can be treated analytically. Unfortunately, some of the assumptions in the analysis break down when the coil size becomes comparable to the flaw size, and the accuracy of the predictions is not known. A purely numerical technique could be applied to the case of tightly coupled coils, where large impedance changes are observed, in order to predict the coil performance more accurately in this practically important regime. This would be more expensive than the present approach since a new numerical calculation would have to be performed for each new flaw type studied since the perturbation condition is violated. However, it should be noted that recent results obtained at Iowa State University using the finite difference techniques show considerable progress in this regard.

3.3 Ultrasonics

3.3.1 Fundamentals of Detectability

A variety of ultrasonic techniques are being developed which could potentially be applied to the problem of sizing internal cracks. These can be characterized in terms of the ratios of wavelength λ to flaw size a as required for their successful application, and range from long wavelength scattering techniques, $\lambda/a<<1$, to imaging techniques, $\lambda/a>>1$. The particular members of this group which can be applied in a given application depend upon the flaw size, the material attenuation and grain noise, and the proximity of the flaw to the material surface. These factors, which limit the choice of ultrasonic frequency and wavelength, are discussed in greater detail below.

To first order, the signal-to-noise ratio of an ultrasonic measurement can be written as

$$S/N = \frac{A(f)e^{2\alpha(f)\ell}}{N_b+N_e+N_g} \qquad (9)$$

where A(f) is the flaw scattering amplitude, $\alpha(f)$ is the material attenuation in nepers/unit length, ℓ is the distance from the transducer to the flaw, and N_b, N_e and N_g are noises associated with scattering from nearby part surfaces and electronic and grain boundary scattering noises, respectively. At low frequencies, $A(f)\propto f^2a^3$ where f is the frequency and a is the flaw radius. At high frequencies, A(f) approaches a constant. N_e is also a constant for all frequencies when measurements are made with a fixed bandwidth. In most metals, $\alpha(f)$ and N_g are both dominated by grain scattering. When ultrasonic frequencies are sufficiently low that the wavelength is large with respect to the grain size, $\alpha(f)\propto f^4$ and $N_g \propto f^2$. N_b depends upon the details of the transducer temporal response. A first estimate suggests that it would vary as the function $e^{kf/\ell}$, where k is a transducer parameter.

From these factors, the composite sketch of signal-to-noise ratio shown in Figure J-18 can be reached. At both low and high frequencies, values of less than 1 are expected with a peak, which may or may not exceed 1 (depending on the material) occurring at an intermediate value of ka. For definiteness, we have shown this peak to occur at ka=1, although this will vary *depending on the specific numerical values of the model parameters corresponding to a* particular physical situation.

Preliminary data, supplied by Jim Doherty of Pratt & Whitney Aircraft for IN100, shows that a signal equal to 50% of that from a No. 1 hole can be detected at 10 MHz with a signal-to-noise ratio of 2. This corresponds to ka of 1.2 where 2a ≈ 0.008 in. If the frequency is doubled, N_g should increase by 4 and the signal-to-noise should drop below unity. Thus, little or no information should be available above 20 MHz, or ka ≈ 2. The low frequency side will also be limited, with the lower limit depending upon the relative values of electronic and grain noise. More precise statements must await a complete analysis of the experimental and material system. *It seems likely, however, that it will be necessary to use wavelengths long, or* comparable to, the flaw size for detection and characterization.

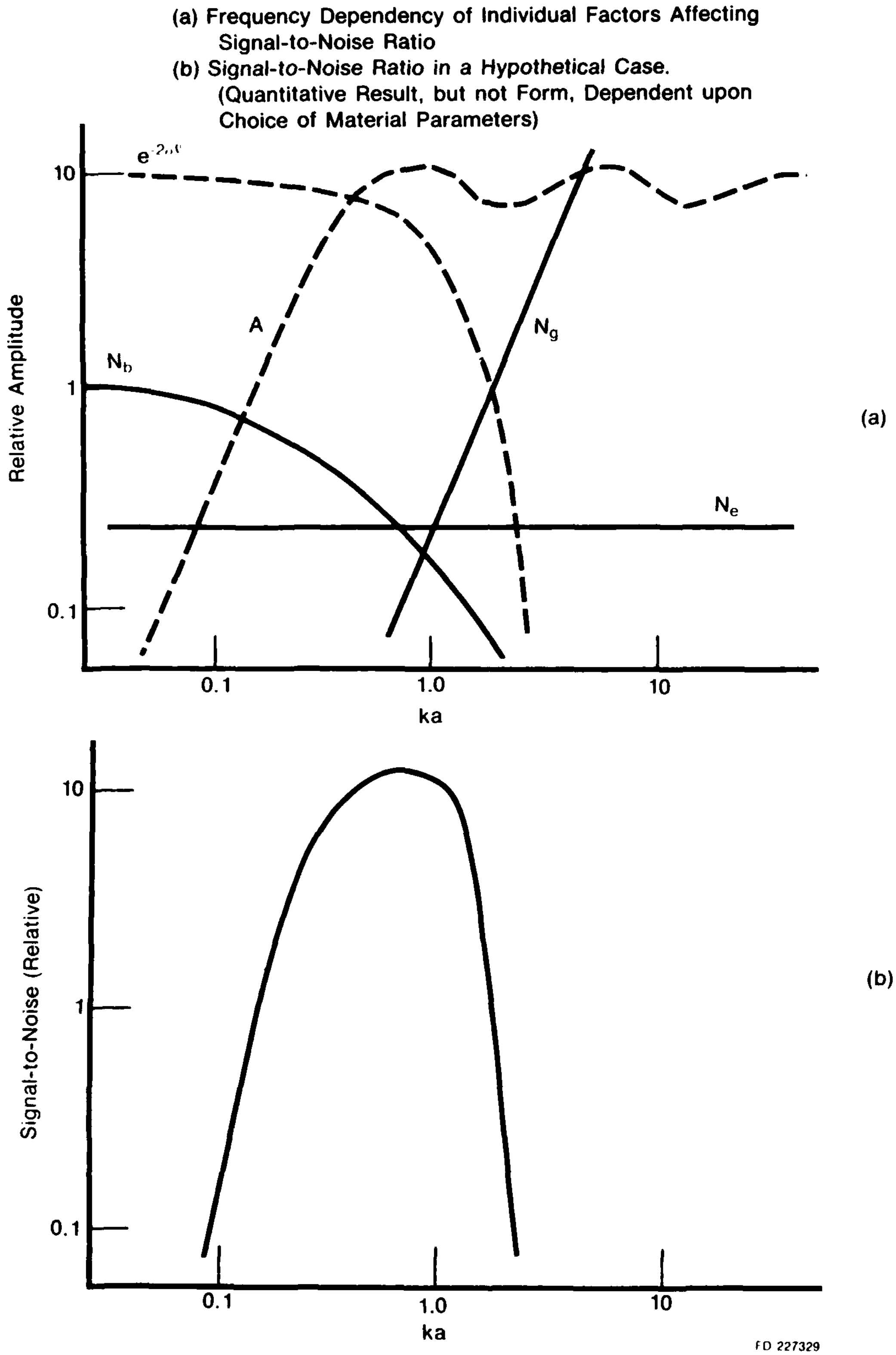

Figure J-18. Schematic View of Measurement Windows for Inversion (a) Frequency Dependency of Individual Factors Affecting Signal-to-Noise Ratio (b) Signal-to-Noise Ratio in a Hypothetical Case. (Quantitative Result, but Not Form, Dependent Upon Choice of Material Parameters)

3.3.2 Long Wavelength Scattering

The long wavelength scattering regime occurs when $ka << 1$, i.e., the wavelength is large with respect to the flaw size. If one performs a spectral analysis of a pitch-catch or pulse-echo signal containing frequency components in this regime, then a Taylor series expansion of the normalized signal amplitude A (i.e., the scattered signal divided by the incident signal) takes the form

$$A(\omega) = A_2\omega^2 + A_3\omega^3 + A_4\omega^4 + \ldots \tag{10}$$

The leading term of this expression, $A_2\omega^2$, is the Rayleigh scattering term. Determination of its coefficient, A_2, at appropriate orientations has been shown to allow a direct determination of the stress intensity factor for elliptical cracks. The technique therefore appears well suited to the evaluation of internal cracks in the web and bore region.

More specifically, Budiansky and Rice (Ref. 3) have shown that, for an elliptical crack, A_2 is given by the expression

$$A_2 \simeq \frac{(1-2\nu)^2}{48V_L^2(2-\nu)r}\,(k_I)_{max}{}^6 \times e_j n_j \left(n_i q_i e_k q_k + \nu n_i e_i \left[\frac{2-\nu}{1-2\nu} - (n_k q_k)^2\right]\right)$$

$$+\ e_j q_j\,(n_i q_i n_k e_k) + \left(\frac{2-\nu}{1-2\nu}\right)\left[(n_i q_i)^2 + \frac{\nu}{1-2\nu}\right]\ , \tag{11}$$

where V_L is the longitudinal wave velocity, ν is Poisson's ratio, r is the distance from the flaw to the receiving transducer, (k_I)max is the value of the reduced stress intensity factor at the point on the flaw circumference at which it assumes its maxima, q is a unit vector in the direction of the incident wave, e is a unit vector perpendicular to the crack face. This result is exact for circular cracks with $\nu=0$. However, it is an excellent approximation for a wide range of parameters, with errors of only about 10% for very elongated elliptical cracks with axis ratios of 0.06 and for values of $\nu=1/3$ or higher. The form of Eq. (11) shows that the maximum reduced stress intensity factor $(k_I)_{max}$, can be directly determined from a measurement of A_2. This, of course, requires an absolute determination of the scattering amplitude. Fortunately, however, A_2 varies as $(k_I)_{max}{}^6$. This means that an error of a factor of 2 in determining A_2 (6 dB error in the absolute scattering measurement) will only produce an error of 12% in the predicted value for $(k_I)_{max}$. This high leverage of the measurement on a key fracture critical parameter of a flaw is one of the most attractive features of the long wavelength approach.

This result is not only useful for measuring stress intensity factors, it also provides a basis for predicting the orientational dependence of scattering from cracks at long wavelengths. The complicated function in brackets in Eq. (11) simply describes the dependence of the signal on the angles of the transmitter, q, and the receiver, e, with respect to the flaw normal. This simplifies to simple trigonometric functions for any specific experimental configuration. Consider, for example, the case illustrated in Figure J-19, which models the web region. For simplicity, we will assume that both the transmitter and receiver are placed in the X, Z plane, which contains the direction of applied stress and hence the anticipated normal to the crack face. Then the angular dependence, in brackets in Eq. (11) becomes

$$= 2\cos\phi\cos\theta\cos(\theta+\phi) + (\cos^2\phi)\left[\frac{2-\nu}{1-2\nu} - (\cos\theta)^2\right]$$

$$+\ \nu\left(\frac{2-\nu}{1-2\nu}\right)\left[(\cos^2\theta) + \frac{\nu}{1-2\nu}\right]. \tag{12}$$

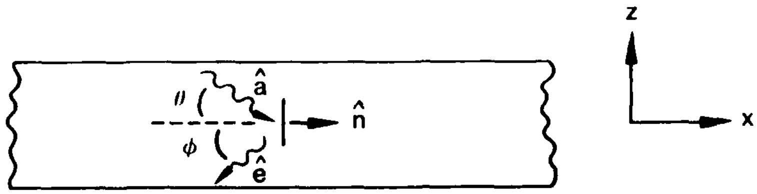

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Figure J-19. Coordinate System Budiansy and Rice Prediction of Long Wavelength Ultrasonic Scattering from Crack in Plate

From the form of this function, we can see that it has a maximum value when $\theta=\phi=0$. For the case of $\nu=1/3$, it has the value 9.33. This is the case of backscattering from the face of the crack, which is physically unrealizable in the plate geometry shown in Figure J-19. When $\theta=\phi=45$ deg, the signal amplitude is reduced to 4.75. Thus, in this 45 deg longitudinal wave pitch-catch configuration, the signal is reduced to 6dB below the maximum pulse-echo signal at normal incidence. When $\theta=90$ deg and $\phi=90$ deg, the amplitude is 1.67. Thus, this edge view pulse-echo signal is reduced to a value 15dB below the broadside pulse-echo signal of the flaw. This corresponds to the signal that would be obtained with a longitudinal probe aimed normal to the surface in Figure J-19. Figure J-20 presents the details of the angular variation of the pulse-echo signal. When assessing these values it must be recalled that there is an additional loss, on the order of 5dB, entailed in operating at long wavelengths (see A(f) in Figure J-18). Thus, the total loss for edge detection of a crack at long wavelength (ka $\sim$0.5) is on the order of 20dB. Referring to the signal-to-noise ratio of 2(6dB) cited in Section 3.3.1 for detecting a crack at normal incidence with a=0.004 in. and ka=1.2 in IN100, the signal-to-noise ratio for edge detection extrapolates to -14dB. However, since electronic noise can be reduced by signal averaging (at the expense of inspection time), and grain noise drops off as f^2 (a 15dB drop in going from ka=1.2 to ka=0.5), the situation is not as bleak as implied above. Nevertheless, achieving reliable edge detection in a case governed by these parameters appears difficult, and pitch-catch configurations should be investigated.

For a measurement made with these angles, or any other set of fixed transducer angle θ and ϕ, the amplitude varies slowly with the orientation of the crack, in general on the order $\cos^2\psi$ where ψ is the deviation of the crack normal from the x-axis in Figure J-19. Thus, for a 20 deg angular error, there would only be a 12% error in A_2 or a 2% error in $(k_I)_{max}$ for the 45 deg pitch-catch technique discussed above. The techniques thus appear quite robust to modest variations in crack orientations.

The state of development of this technique is fairly early. The theoretical work of Budiansky and Rice has been followed by a few related analytical papers. One direct laboratory demonstration of the direct measurement of stress intensity factors has been made at Stanford (Ref. 4). In that work, Rayleigh waves were used to measure the long wavelength backscattering of ultrasound from a surface crack in a glass ceramic. From analysis equivalent to that presented above, a stress intensity factor and a failure load were predicted and compared to experiment. The results, presented in Figure J-21, show an excellent agreement. The fact that the predicted loads were systematically 15% less than the actual failure loads was later explained in terms of a slow crack growth, and hence increase in stress intensity, during loading prior to failure. More recent unpublished results at Stanford and Berkeley have shown that this approach can be used to predict the failure strength of surface cracks produced by machining damage in ceramics. Other laboratory demonstrations of the same basic principles have been used to measure geometric parameters of ellipsoidal voids.

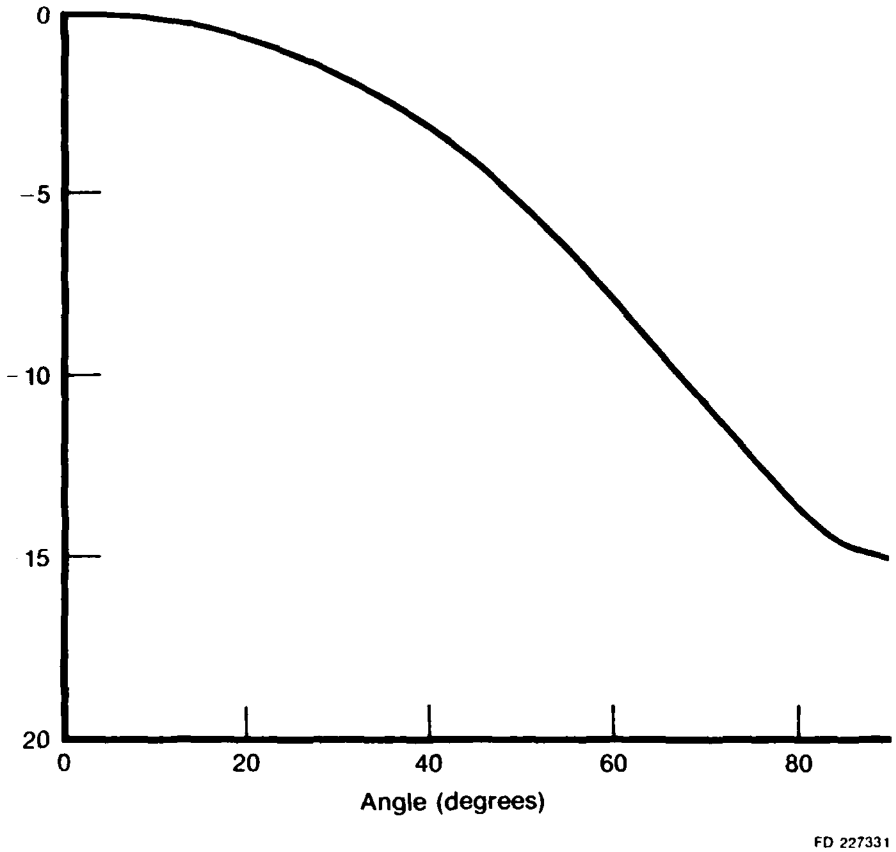

Figure J-20. Angular Dependence of Long Wavelength, Pulse-Echo Scattering for an Elliptical Crack

A number of practical questions must be answered before this technique can be incorporated in a system to be used in a production or maintenance environment. These fall into two categories, the first of which relates to the degree to which actual fatigue cracks have topographies that match the assumptions of the theory. In the analysis, the crack is modeled by a pair of elliptical, planar, stress-free surfaces separated by an infinitesimal distance. In fact, the surface may be rough and furthermore, there may be partial contact due to closure stresses. The effect of roughness can probably be neglected because of the large ultrasonic wavelength. However, the effects of closure need to be experimentally assessed. A start in this direction is being made in Reference 5, in which a constant correction factor has been developed for the particular cracks studied in ceramics.

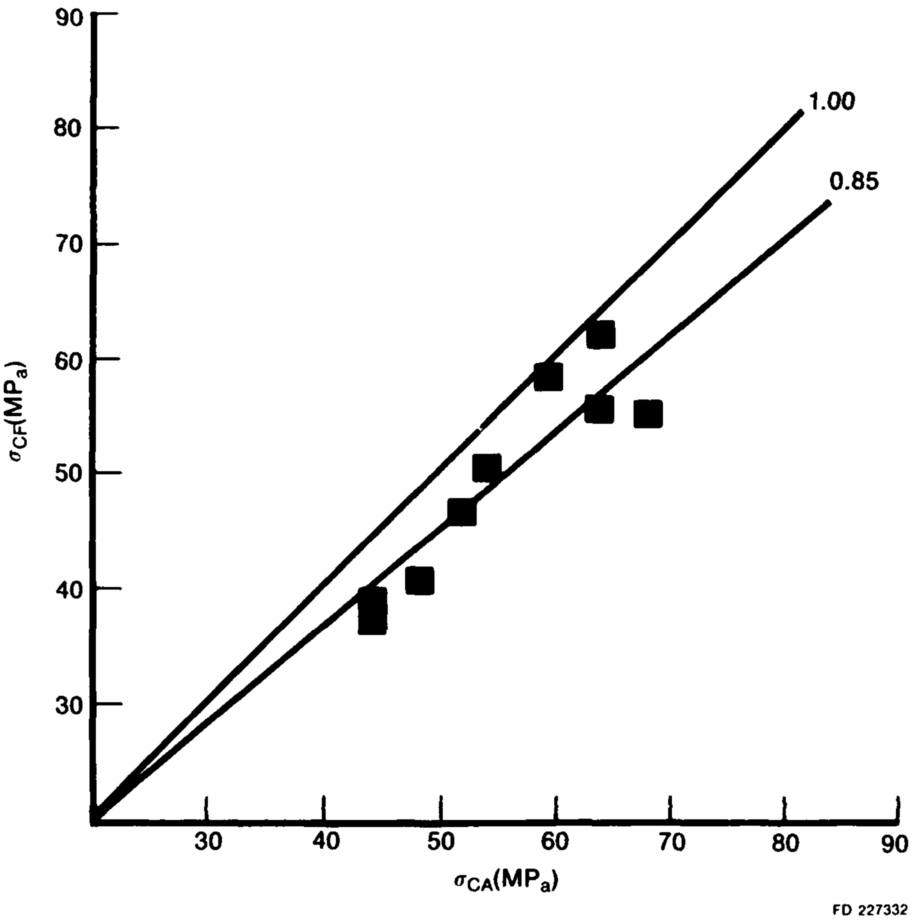

Figure J-21. Actual Stress vs Acoustically Predicted Fracture Stress (Figure from Stanford University)

The second set of questions relates to experimental difficulties in measuring the long wavelength scattering parameters. Examples of problems include interferring grain scattering noise, alluded to above, and difficulty due to interferring signals from surfaces. Some of the problems associated with estimating A_2 from noisy data have been theoretically addressed by Richardson and Elsley (Ref. 6). The surface problem occurs because, at the low frequencies at which the measurements must be made, resolution is limited. In general, one needs scattering information for frequencies such that ka<0.5. For the numerical example given above, this corresponds to frequencies below 4 MHz. For an ideal transducer with classical tripolar response which has no reverberations after this three half-cycle period, this implies that the flaw should be no closer than 1.8 mm or 0.074 in. from the surface if it is to be completely resolved. Since real transducers have internal reverberations and lower frequency information would be desired, the realistic number may be considerably greater. Approaches for overcoming these problems are available. For example, the near-surface reflection problem can be reduced by placing transmitter and receiver at positions for which the specularly reflected surface signal does not occur. However, Eq. (11) shows that significant flaw scattering signals will still be found. Some preliminary answers to these questions may be obtained in the Test Bed program at the Rockwell International Science Center. However, a measurement technique development program is required to assess the extent to which these problems can be practically overcome.

3.3.3 Inverse Born Scattering

The inversion technique which has received the most development effort, and the one which works in the regime ka$\sim$1 where signal-to-noise ratio is expected to be the maximum, is the inverse Born approximation. This has a variety of formulations, some in the time domain and some in the frequency domain (Ref. 7). Here only a sketch of these details will be given, along with a review of assessment of the algorithm's sensitivity to bandwidth and other parameters.

The algorithm is simplest to understand in the time domain. Figure J-22 schematically illustrates an ultrasonic backscattered signal from a flaw. It can be seen that there are two sets of arrivals. The first signal represents the signal reflected from the front surface of the flaw. The later signals can arise from a variety of causes, depending on the physical nature of the flaw. For a void, these are produced by the "creep rays" which propagate around its periphery. For an inclusion, waves propagating or refracting through the inclusion produce these signals, and for cracks, signals diffracted from the crack edges are dominant.

In any event, it has been rigorously established that, for flaws with a center of inversion symmetry, the time corresponding to this center ($t=T_c$ in Figure J-22) can be directly determined from the long wavelength component of the scattering. This can be formally argued in the following manner. Scattering theory shows that, for flaws with a center of inversion symmetry and the origin of time placed at the position corresponding to the center of the flaw, the second coefficient in Eq. (11) vanishes and

$$A(\omega) = A_2\omega^2 + 0(\omega)^4 \tag{13}$$

However, one does not initially know the proper choice of time origin. Instead, a first guess must be made by looking at the signals. For example, $t=T_c+\tau$ might be selected, as shown in Figure J-22. This amounts to a shift in the origin of time, and using the shift theorem for Fourier integrals, Eq. (13) must be rewritten in the new time coordinate system with origin at $t=T_c+\tau$

$$A(\omega') \quad A(\omega)e^{j\omega\tau} \sim A_2\omega^2 + jA_2\tau\omega^3 + 0(\omega^4) \tag{14}$$

If one can then deduce A_2 and $A_3 = jA_2\tau$ from spectral analysis of the ultrasonic signal, then τ can be directly determined from the equation

$$\tau = \frac{A_3}{jA_2} \tag{15}$$

Since the directly observable time of arrival of a reflection from the surface of the flaw is T_F, the flaw radius (or more precisely the distance from flaw center to front surface tangent plane) is equal to

$$r = \frac{(T_c - T_F)}{2} V \tag{16}$$

where V is the velocity of the ultrasonic wave.

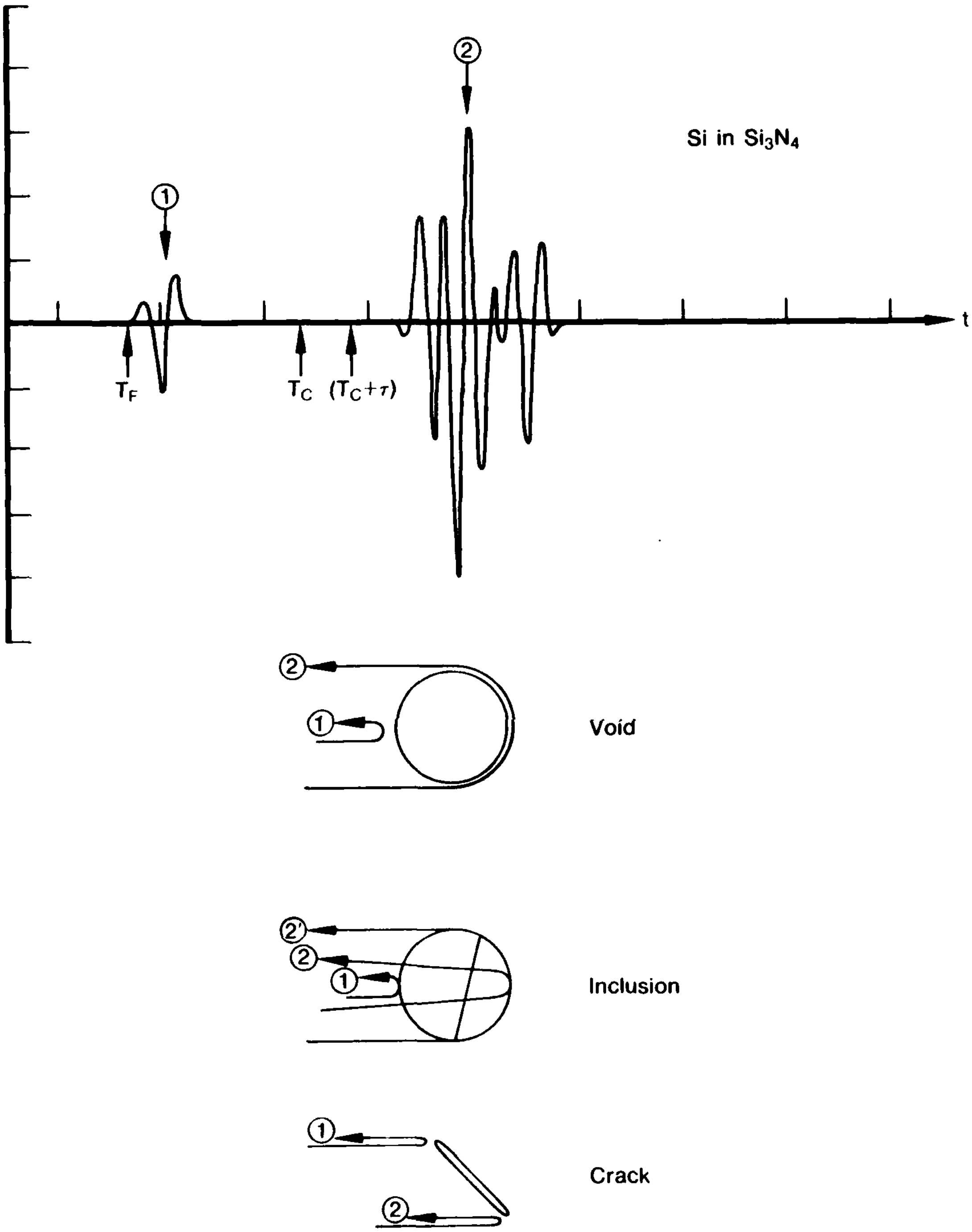

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Figure J-22. Typical Waveform and Possible Wavepaths for Various Flaws in Pulse-Echo Mode

In practice, because of bandwidth limits, the various times are not as clearly delineated as shown in Figure J-21. In these cases, a frequency domain version of the algorithm is often used which is essentially equivalent to the above approach. In such cases, the output of the algorithm is a plot of a characteristic function, $\gamma(r)$, which is defined to be unity inside the flaw and zero outside of it. In practice, the bandlimited nature of real data will produce a smoothing of the predicted characteristic function. The flaw radius can then be estimated using a number of criteria. Two that have proved useful are the value of r at which the characteristic function drops to 50% of its peak value, or the area under the plot of the characteristic function vs r plot, divided by the peak value.

An extensive test of this algorithm has been made for the case of spherical voids, including the influences of both signal-to-noise ratio and bandwidth (8) on the accuracy of the flaw size predictions. Figures J-23 and J-24 summarize the result of the latter assessment.

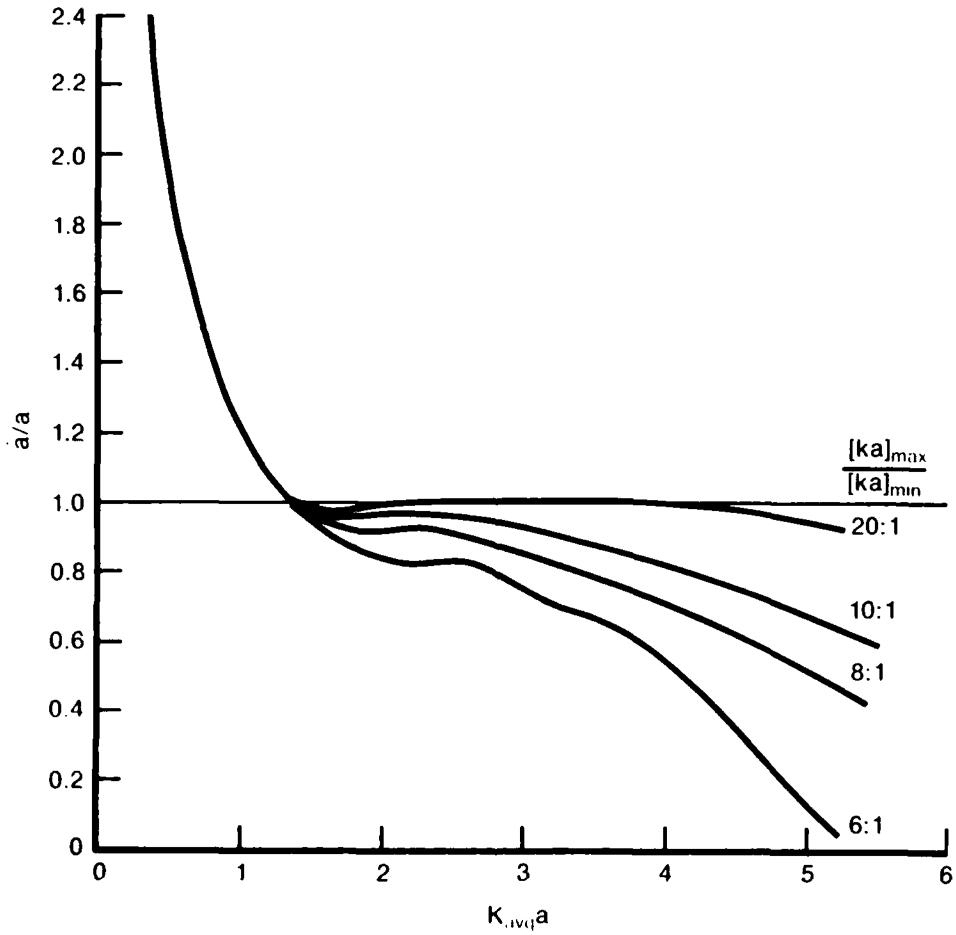


Figure J-23. Accuracy of Born Inversion vs Transducer Center Frequency and Bandwidth (Figure from Rockwell International)

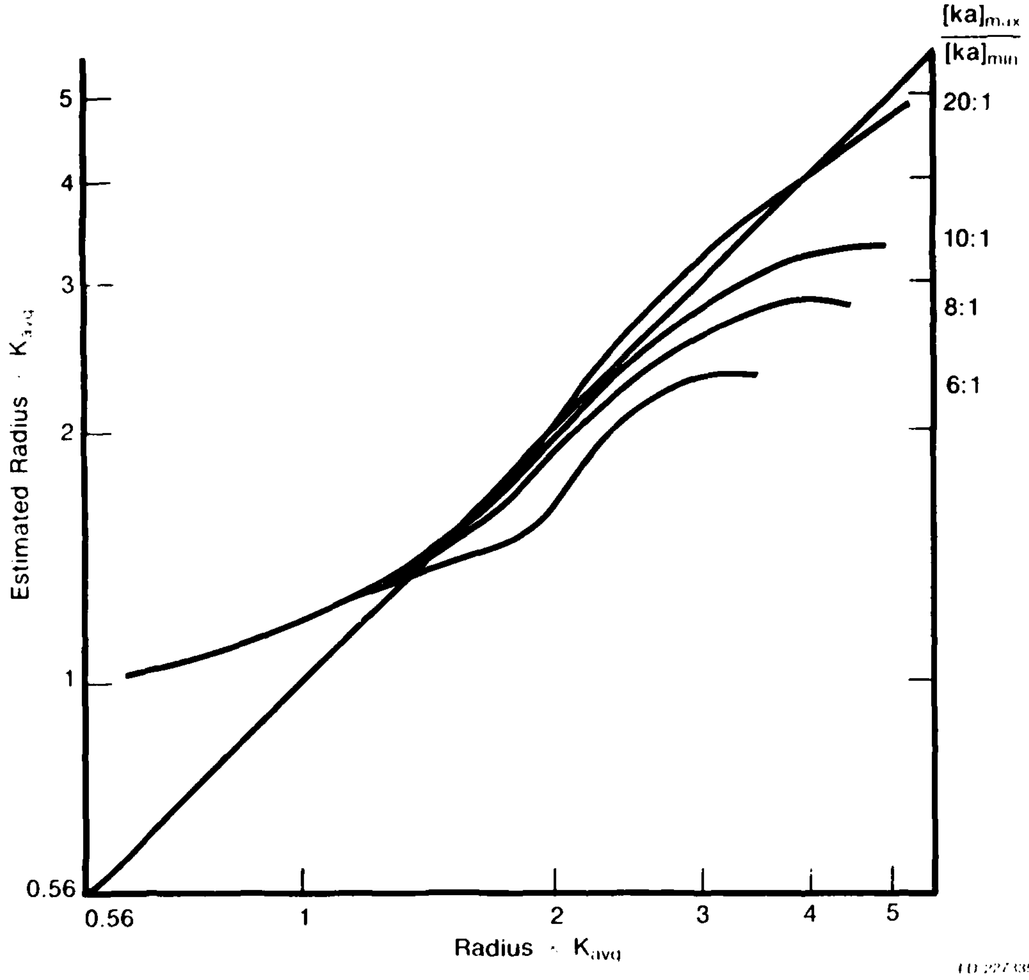


Figure J-24. Estimated Flaw Size vs True Flaw Size for Several Transducer Bandwidths Using Born Inversion (Figure from Rockwell International)

Specifically, the algorithm has been used to predict the estimated radius a of a flaw having actual radius a. A Hanning window has been used to bandlimit theoretical predictions of the scattering from a sphere to simulate actual data as measured through the transfer function of a piezoelectric transducer. In the figure captions, Kavg is the wave number at the center frequency of the window and (ka)max and (ka)min are the values of ka at the high and low frequency zeroes of the Hanning window. The same data is used to plot the two figures. Figure J-23 plots the ratio of estimated to actual radius, a/a, as a function of the center frequency of the window. Several curves are plotted for different bandwidths. From this data, it can be seen that, for a 6:1 bandwidth, best results are obtained for ka ~ 1.3. As bandwidth increases, accurate results are obtained over a broader range of center frequencies. The same results are used to plot in Figure J-24, but here the estimated radius is plotted vs the actual radius. This result could be used as a calibration to extend the usefulness of the results. If one knows kavg and |ka|max/|ka|min, which are both transducer parameters, then the actual radius can be determined from the estimated radius and the appropriate calibration curve.

In addition to the theoretical results presented above, the algorithm has been applied extensively to experimental data for the scattering from ellipsoidal cavities. It has been shown that the approach which measures the radius of a sphere, also measures the front surface tangent plane to center distance for an oblate spheroid, and hence the theoretically predicted performance should apply. In general, this has been found to be the case.

Because it operates best in the regime $ka \simeq 1$, which is where maximum flaw detectability occurs, and because it has received the most detailed evaluation, the inverse Born is the most likely ultrasonic candidate for incorporation into an automatic RFC system. Three questions need to be addressed to ensure that this will be successful. First, as can be seen from Figure J-23, it is necessary to have the bandwidth of the transducer positioned properly with respect to the flaw radius, i.e., $k_{avg}\, a \approx 1$ in order to get accurate results. As shown in Figure J-24, the calibration curve concept can be used to extend this range, but one must "be in the right ballpark" to get optimum results. Thus, it is necessary to use some auxilary information before applying the inverse Born to obtain accurate sizing. One approach uses long wavelength scattering information, as has been done to an extent by Richardson and Elsley (Ref. 6), to accomplish this. Another would use a focused high frequency probe to establish that the flaw size is less than the resolution limit of that probe, and then apply the inverse Born. Procedures of this sort are presently being developed in the Rockwell Test Bed program.

A second difficulty lies in the determination of the time τ which fixes the center of the flaw. The data presented in Figures J-23 and J-24 assumed that this had been precisely determined. Further analysis shows that the accuracy of the technique degrades if this parameter is not determined with sufficient precision (Ref. 9). If low frequency information is rejected by the transducer bandwidth, the determination of τ from Eq. (15) may not be sufficiently accurate. A number of promising approaches to determining τ are being evaluated, but more effort is needed in order to make them fully automatic.

The final question resides in the fact that the inverse Born technique has been developed for, and evaluated on, volumetric voids. In principle, it can be applied to cracks since (a) cracks have the center of inversion symmetry that is necessary for the centroid determination and, (b) a crack is the limiting case of an oblate spheroid as the ellipticity goes to zero. Preliminary theoretical results confirm this speculation (Refs. 10 and 11). In practice, it will be necessary for the signals backscattered from the crack edges at nonspecular incidence to be detectable. If this occurs, then application should proceed successfully, even when these cannot be resolved in time.

3.3.4 Fourier Inversion Integral for Cracks

At somewhat higher frequencies, short wavelength techniques have been developed for interrogating crack-like flaws (Ref. 12). These are based on a physical elastodynamics approximation to the forward scattering problem, which is analogous to the physical optics approximation often used in electromagnetic problems. The approach has not received the same intensive study as the inverse Born, or long wavelength, approximations have. However, from the limited effort that has been expended, it appears to hold considerable promise.

Experimentally, the approach is based upon the measurement of the frequency dependence of the longitudinal wave scattering at two or more sets of scattering angles. Two specific approaches to sizing flaws have been proposed, one of which has been evaluated on experimental data. In this, spectra of the scattering was measured at several angles and used to define the period (Δf) average of the amplitude modulation (i.e., the *ripple*) of the spectra. This period, in turn, defined the flaw dimensions via an inversion function. From an intuitive point of view, this approach may be considered to be a rigorous specification of some of the spectroscopic flaw sizing approaches that have been proposed over the past years. Figures J-25 and J-26 present the results of this technique when used to size a 2500 μm penny shaped crack.

Scattering Angle (θ'_L)	Period of Average Amplitude Modulation $(\Delta f)_{ave}$ (in MHz)
35	2.18
40	1.87
45	1.83
50	1.68
55	1.60
60	1.47
65	1.39

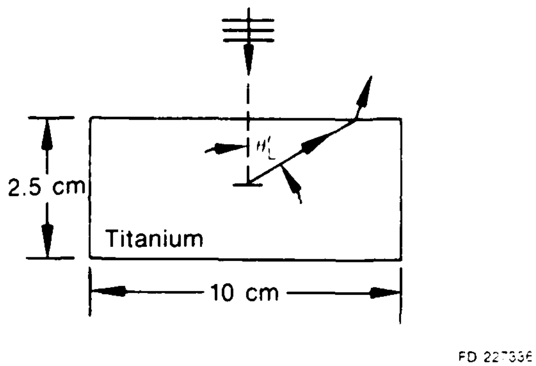


Figure J-25. Period of Amplitude Modulation for Several Angles of Scattering from a 5000μm Diameter Penny Shaped Crack (Figure from Northwestern University)

Angles	(degrees)	Radius	Crack Angle
65.0	35.0	2497.9	89.73
65.0	40.0	2357.4	87.50
65.0	45.0	2641.3	−88.29
65.0	50.0	2663.1	−88.01
65.0	55.0	2965.8	−84.62
65.0	60.0	2775.0	−86.66
35.0	40.0	3307.1	−85.83
35.0	45.0	2180.3	87.03
35.0	50.0	2313.9	88.26
35.0	55.0	2241.6	87.62
35.0	60.0	2436.0	89.26

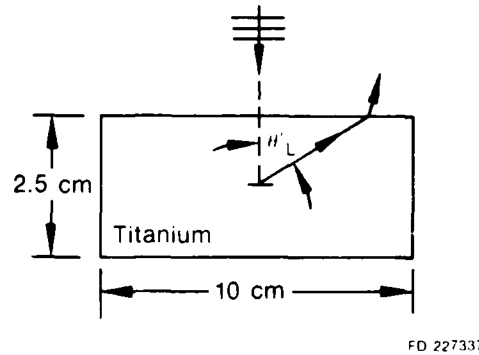


Figure J-26. Results of Fourier Integral Inversion Procedure for 5000μm Diameter Penny Shaped Crack. Measurements of the Period of Amplitude Modulation at Two Angles are Independently Used To Predict Crack Radius and Angle (Figure from Northwestern University)

As might be expected, this technique requires somewhat more complete spectral information than the inverse Born. Curves analogous to Figures J-23 and J-24 have not been developed. However, it has been suggested that $1 < ka \leq 6$ might be a useful frequency band for the application of this technique.

As the sketchiness of the above discussion implies, evaluation of the practical aspects of these techniques are one to two years behind the inverse Born approach. This is not to imply that they are less useful or accurate, but only that their study has been more recently initiated.

Future programs thus need to (1) assess the effects of noise, limited bandwidth, and limited aperture on these techniques, and (2) apply the techniques to real fatigue cracks.

3.3.5 Adaptive Learning Techniques

Adaptive learning techniques have also been developed for sizing surface cracks (Ref. 13). In this case, the same theories used as the basis for the Fourier inversion integral technique discussed in Paragraph 3.3.4 above were used to produce the training set of waveforms. The specific predictor developed was based on 19 measurements made in a conical measurement window with a 60 deg half-angle. This empirical function was trained on theoretically derived spectra corresponding to real frequencies of 1 to 9 MHz and crack radii varying from 0.3 to 2.5 mm. Thus, the range of ka spanned by the training set was 0.31 to 22.3. The network was then tested with experimental data in the same frequency range with dimensions ranging from 0.7 to 1.0 mm. Thus, for the experiments, ka ranged from 0.72 to 6.51 for the smallest dimension, to 1.5 to 13 for the largest dimension. The adaptive learning predictors were based on the total spectral power, the ripple frequency discussed above in subsection 4, and the spatial variation of these parameters over the 19 transducer positions. Figure J-27 presents the results of evaluating the networks on four flaws.

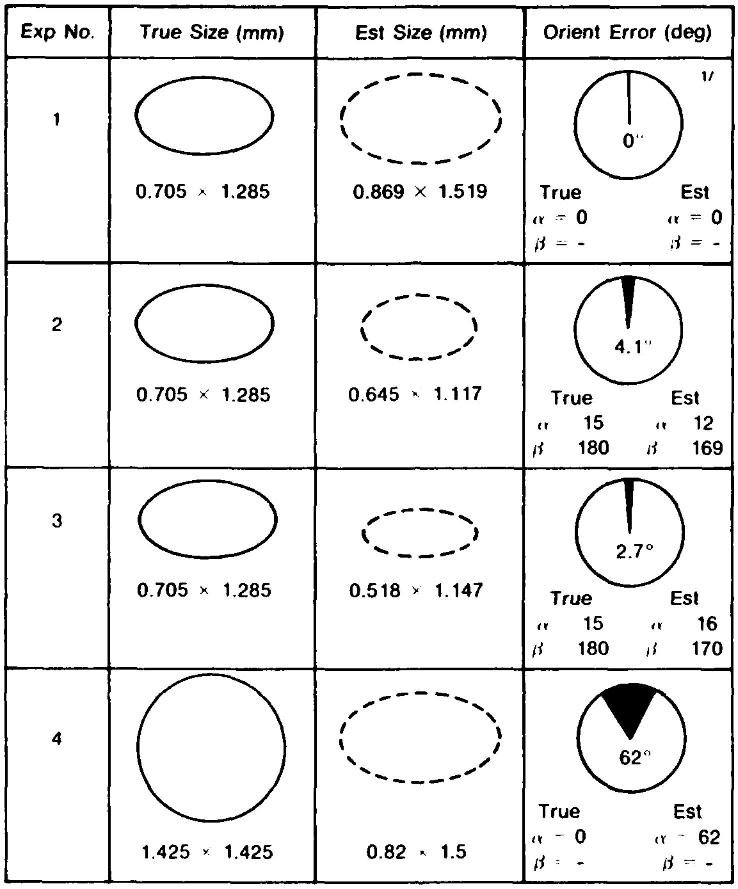
This technique is very close to reduction to practice from the point of view of being in the form of an algorithm which can be automatically applied with available hardware such as the instrumentation suppled by the vendor. Three questions remain to be answered. First, the J-19 transducer scheme used in this demonstration would probably not be appropriate for the RFC geometry and retraining would be required. Second, as for the other cases, evaluation on real fatigue cracks is required. Third, the range of ka values went up to 13 in this demonstration, and this might be beyond the value permitted by the grain noise. Assessment of this point must be made.

3.3.6 Imaging Techniques

Imaging techniques require $ka > 6$, and are probably prohibited by grain scattering interference for the small flaws of interest. However, for completeness, they will be briefly mentioned. Simple focused transducers are ready today and could be used in a pitch catch scheme. However, the time required to scan a 0.005-in. focal spot through the entire volume of interest would probably be prohibitive. A variety of ways to rapidly scan a beam, based on electronically switching the signals received at an array of piezoelectric elements, are under development. However, it is not believed that they will be ready for application to this problem within the required time frame.

3.3.7 Theoretical Assessment of System Performance

As in the case of eddy currents, serious consideration should be given to using recently developed theoretical tools to design and evaluate system performance. An example of how this might be done is presented in the discussion of long wavelength scattering in Section 2. Another point which should be considered is the use of statistical estimation theory (Ref. 9) techniques to probabilistically assess the errors of the experimentally predicted flaw sizes so that the NDE output may be properly combined with probabilistic fracture mechanics.



Exp No.	True Size (mm)	Est Size (mm)	Orient Error (deg) [1/]
1	0.705 × 1.285	0.869 × 1.519	0°; True $\alpha = 0$, $\beta = -$; Est $\alpha = 0$, $\beta = -$
2	0.705 × 1.285	0.645 × 1.117	4.1°; True α 15, β 180; Est α 12, β 169
3	0.705 × 1.285	0.518 × 1.147	2.7°; True α 15, β 180; Est α 16, β 170
4	1.425 × 1.425	0.82 × 1.5	62°; True $\alpha = 0$, $\beta = -$; Est $\alpha = 62$, $\beta = -$

1/Orientation Error $\cos^{-1} [X_{true}X_{est} + Y_{true}Y_{est} + Z_{true}Z_{est}]$

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Figure J-27. Elliptical Crack Inversion Results (Exp. Data) (Figure from Adaptronics, Inc.)

3.4 Microfocus X-rays

One of the objectives of an RFC measurement system is to achieve 100% volumetric inspection. In principal, ultrasonics provides this capability. In practice, however, the complex geometries of turbine rotor components either make ultrasonic access to certain regions impossible due to refraction at the surface or generate a complex set of background signals due to boundary reflections. For these two reasons there are substantial interior regions which cannot be inspected ultrasonically.

X-rays provide an alternative, whole field inspection capability. They have, however, traditionally suffered from the problems of poor resolution, so they could not be considered as candidates for the RFC problem when flaws on the order of 0.005 in. may have to be found. Recent developments in microfocus X-ray techniques have removed some of these deficiencies, and so the potential of X-ray approaches needs to be re-evaluated.

Microfocus X-rays are characterized by an X-ray source size (10-100 μm) which is much smaller than that of more conventional radiography systems (1-5 mm). Because of this it is possible to operate at a large object to screen distance without loss of image detail. This, in turn, allows one to avoid image resolution limits imposed by film, and to achieve a number of other applications discussed in detail in Reference 15. A state-of-the-art instrument, the E12, is manufactured in England by Wells Krautkramer, Ltd. This instrument has a 10 μm focal spot size at voltages of 30-80 kV and beam currents up to 1mA. cost is approximately $130,000.

The performance of the E12 has been documented in a series of application notes and technical papers (15,16). Included among the demonstrations are detection of distributions of 10-30 μm (0.4-1.2 mil) pores in IN100 turbine blades, detection of 20 μm (0.8 mil) steel wire in IN100 turbine blades, turbine blade inspection rates of 1000 per week (25 sec/image) using gadolinium oxysulphide fluorescent screens, and detection of thermal fatigue cracks in aluminum. It is stated that 8 mm of steel or higher can be inspected, but it is clear that the kV ceiling naturally limits the thickness of turbine disk sections that can be inspected.

In light of these performance specifications, the applicability of the E12 to RFC of turbine rotor components can be evaluated. As noted above, the kV ceiling limits the thickness of components which can be inspected. Furthermore, because of the high orientation sensitivity of images from tight cracks using any X-ray system, whole field inspection applications appear unpromising even if the penetration problem can be overcome. However, the potential of this technique as a back-up system to ultrasonics appears good. It is possible that such high amplifications may be required in the ultrasonic inspection to achieve the desired sensitivity that a significant number of false calls will be encountered. In this case, the microfocus X-rays could be used as a back-up system to verify the ultrasonic calls. Here it might be possible to make multiple radiographs of a given part with orientation varied since only a few parts would be interrogated. Section thickness would again be limited by the kV ceiling, but larger sections may be handled in the future as technological advances increase this ceiling.

3.5 Optical Techniques

Optical techniques, in the form of visual inspection, are probably the most widely used form of nondestructive testing. For the case of surface crack detection, this is commonly used in the form of a visual detection of a penetrant indication. An in-progress program at the Rockwell International Science Center is studying whether more sophisticated technology can be brought to bear on this problem area.

The basic premise is that since the wavelength of light is on the order of a μm, then features of this size should be able to be resolved in a suitably designed optical system. Unfortunately, most optical systems used in field NDT today are far from optimum. The basic program, then, is to design and construct a high quality optical system to scan the interior of a bolthole, and to use an image analysis system to identify and size linear image features which will correspond to surface breaking cracks. This is being pursued as a part of the DARPA sponsored RFC research program.

Preliminary research results have been obtained which support the validity of this concept (Ref. 17). It has been shown on flat plates that (a) tight fatigue cracks can be optically detected with high resolution optics, and (b) that the lengths of these can be automatically determined using commercially available image analysis equipment. A demonstration system is now being constructed to apply these ideas to the interior of a turbine disk bolthole.

The ultimate applicability of these ideas to RFC depends upon (a) whether the surface is sufficiently clean for the crack to be visible, and (b) whether cracks which must be detected do, in fact, break the surface. In the former regard, it should be noted that the same conditions

apply to penetrant inspection, and serious consideration is being given to surface preparation that would serve the needs of the optical as well as penetrant technique. It may be found that the ultimate system incorporates the automatic optical read-out and sizing of penetrant indications.

The comments with respect to buried flaws apply to penetrant and microwave eddy current techniques as well. At this point it appears that flaw detection will be satisfactory, but that sizing errors will be found due to the presence of subsurface crack segments such as were found in the Failure Analysis Associates and work reported in Paragraph 2.2. It should be noted that the Rockwell program recognizes this potential sizing deficiency and therefore plans to use the optical technique primarily for high speed detection. New ultrasonic techniques have been proposed for sizing. However, since no data have been obtained using these, they are not included in this discussion.

3.6 Thermal Waves (Photoacoustics)

If the surface of a solid is periodically heated and cooled, thermal waves will be excited which satisfy the diffusion equation and are attenuated exponentially as they propagate into the material. These waves have many features in common with eddy currents and should find important application where discontinuities in heat flow, rather than current flow, are associated with flaws. The waves can be excited by a variety of means, such as illumination of the surface of a material by a modulated laser or electron beam. They can be detected by sensing the acoustic waves radiated into the surrounding air by the periodic expansion of the near-surface air layer. This is done by using a microphone or by direct infrared temperature sensing. They have been shown to be sensitive to cracks in ceramic turbine components (Ref. 18), to plastic deformation in metals (Ref. 19), and compositional variations in semiconductors (Ref. 20). It appears likely that this will become an important new tool in the NDE arsenal. However, development is in an early stage, and application to RFC systems cannot be expected for several years.

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